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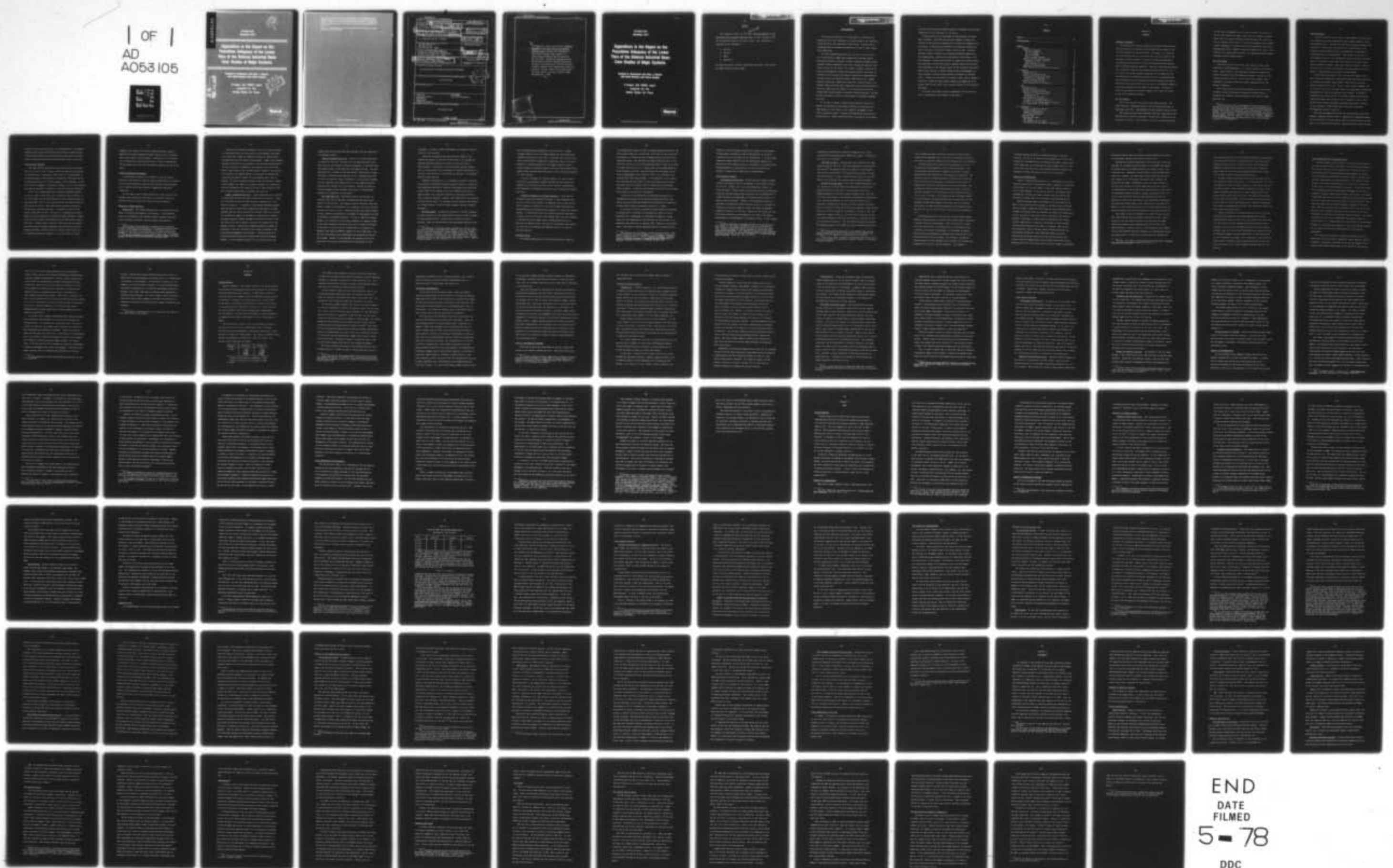

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Appendixes to the Report on the Peacetime Adequacy of the Lower Tiers of the Defense Industrial Base: Case Studies of Major Systems

Geneese G. Baumbusch and Alvin J. Harman
with David Dreyfuss and Arturo Gandara

A Project AIR FORCE report
prepared for the
United States Air Force

Rand
SANTA MONICA, CA. 90406

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This companion volume to R-2184/1-AF, Peacetime Adequacy of the Lower Tiers of the Defense Industrial Base, presents the information, or case studies, derived from a survey of 13 system program offices at two Air Force product divisions: Aeronautical Systems Division and the Space and Missile Systems Organization. Included in the survey were 7 aircraft programs, 2 missile programs, and 4 communication satellite programs. The case studies are organized under four major topics: Aircraft, Maverick, SRAM, and Spacecraft. (DGS)

R-2184/2-AF
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PREFACE

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This companion volume to R-2184/1-AF, Peacetime Adequacy of the Lower Tiers of the Defense Industrial Base, contains information from the data-gathering phase of the parent study. This information is organized in four appendixes:

A. Aircraft

B. Maverick

C. SRAM

D. Spacecraft

The research was part of Rand's "Industrial Base Study" under Project AIR FORCE (formerly Project RAND).

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The authors are grateful to a large number of individuals and organizations for their assistance in various stages of the industrial base study and in the preparation of this report. We would like to acknowledge here the guidance and assistance of some of these, within space limitations.

Air Force representatives from the C-5, A-7, A-10, F-16, F-15, F-4, F-111, Maverick, SRAM, Space Communications Systems, Defense Meterological Satellite Systems, and Space Navigation Systems programs provided valuable information about their programs and important additional contacts for our survey. Mr. Ralph C. Johnston, Assistant for Acquisition Management, Aeronautical Systems Division, was helpful in arranging initial contacts with System Program Office representatives from the aircraft and missile programs. ARF Products Inc., Boeing Aerospace Corporation, Eagle-Picher Industries, General Electric Corporation (Rocket Case Operation), Hughes Aircraft Corporation (Missile Division), Hughes Electron Dynamics, Litton Microwave Electronics, Teledyne MEC, Thiokol Chemical Corporation (Wasatch Division), and TRW provided information used in the case studies of individual programs and firms.

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We would also like to acknowledge the contributions of several Rand colleagues. David Dreyfuss and Arturo Gandara conducted the research on the spacecraft programs that is reported as Appendix D of this report. Richard Fallon assembled and interpreted relevant economics literature on barriers to market entry and exit. His work provided a useful framework for evaluating information gathered in our program survey. Patricia Dey participated in the survey of aircraft programs. Michael Rich reviewed the legal and procedural framework applicable to multiyear buying of defense products and provided other assistance in the research effort and the writing of this report. Robert Perry, Director of Rand's Systems Acquisition Management research program, provided valuable guidance throughout our research effort. Finally, we are grateful to George C. Eads, Adele P. Massell, and Giles K. Smith for their helpful comments and suggestions on an earlier draft of this report, and to Dorothy Stewart for her editorial assistance.

Of course, the authors alone are responsible for any errors of fact or interpretation that remain in this report.

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Appendix A

AIRCRAFT

OVERVIEW OF PROGRAMS

Our information on aircraft programs was gathered almost entirely from interviews in the relevant System Program Offices (SPOs) at the Air Force Aeronautical Systems Division. Although it is, therefore, less detailed than some of the material that follows on missiles and spacecraft, it does provide an overview of problems encountered by airframe prime contractors in attracting and maintaining an adequate base of subcontractors and suppliers. Since the seven programs surveyed are in different stages of the acquisition process--the F-111, C-5, F-4, and A-7 are in the inventory and mostly out of production; the F-15 and A-10 are in production; and the F-16 is in development with early preparation for a multinational production program--the kinds of difficulties encountered with the lower tiers of the defense industrial base varied, depending on the status of the program. We begin our review of the material on aircraft programs with a brief description of each of the programs surveyed.

The F-15 Program

The F-15 is the Air Force's first-line fighter aircraft. The prime contractor is McDonnell Douglas, and the airplane has been in production since 1972. Approximately 372 were produced through FY 1976.

The program involves about 300 major first-tier subcontractors and 1000 more minor first-tier suppliers, virtually all of whom have firm-fixed-price contracts. The philosophy of Air Force program management

has been that of engagement--i.e., to get as close to the prime contractor (and, through the prime, to the subs) as is legally possible (given that the two-party contract between the prime and a given sub does not include the Air Force).* Air Force oversight of the airframe contract management is carried out by the 250-person Air Force Plant Representative Office (AFPRO) at McDonnell Douglas in St. Louis. Pratt & Whitney, the engine prime contractor, has approximately 200 resident government-contract administrators.

The A-10 Program

The A-10 is the Air Force's new close support aircraft being developed by Fairchild-Republic. It is just entering the production phase. General Electric, the other major contractor, produces the engine and armament--the GAU-8 30mm gun--through a contractual relationship with the Air Force. The Air Force then furnishes these subsystems to Fairchild, which has overall responsibility for the system's integration.

Most of the subcontractors have firm-fixed price contracts that include an inflation provision to adjust the contract prices to compensate for unusually large fluctuations in the costs of labor, materials, etc.

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*The policy of Air Force involvement in the prime contractor's affairs as it affects the prime's treatment of its subcontractors has been debated in the courts in well-known litigation between McDonnell Douglas and the Garrett Corporation, a major subcontractor in the F-15 program. For an analysis of this dispute and its broader implications, see "Subcontract Disputes: The Case of the Missing Remedy?" Federal Contracts Report, No. 550, October 7, 1974, p. K-3. For our discussion of Air Force responsibility for and authority over subcontracting, see Section V in R-2184/1-AF.

The F-16 Program

The F-16 is the Air Force's new air combat fighter that was chosen in a technology prototype competition between General Dynamics' YF-16 and Northrop's YF-17. The F-16 has been in full-scale development since early 1975. Production of the aircraft will be undertaken by four European nations--Denmark, Norway, the Netherlands, and Belgium--in cooperation with U.S. manufacturers. Forty percent of the value of the European aircraft is to be produced in the four European countries; and up to 50 percent of the value of any future third-country sales will be produced in Europe. About 1100 F-16s are already on order for use by the U.S. Air Force, the European consortium members, and Iran. However, ultimate sales are expected to be much higher.

The multinational nature of the F-16 obviously suggests a much more complicated framework of relationships among the prime contractors for airframe and engines, their domestic subcontractors, European associate subcontractors, etc., than is typical in most programs. But it is really too soon to tell what effect this complicated co-production arrangement will have on the outcome of the program. According to representatives of the F-16 SPO, if potential subcontractors had any reservations about participation in such a program, it was not discernible when requests were made for program participants. Because of the potential for high-volume sales of the F-16, firms were "breaking down the door to get in."

There are approximately 60 major U.S. subcontractors in the F-16 program. Emphasis has been placed on commonality of subsystems between the F-15 and F-16; 10 of the subs for the F-16 are also major F-15 subs. Most of the contracts (both with U.S. suppliers and with those European

suppliers that have been selected) are firm-fixed price. The General Dynamics prime contract with the Air Force contains a newly created contract clause that gives the Air Force more authority over certain kinds of subcontracting decisions than has been typical in the past.

Other Aircraft Programs

The other aircraft program offices surveyed cover four systems--the F-4, A-7, F-111, and C-5--each of which has been in the inventory for several years. Consequently, SPO concern for, and knowledge of, problems relating to subcontractors and suppliers (firms that may now be dealing directly with a different agency of the government, the Air Force Logistics Command, as suppliers of spares, etc.) is less extensive than might be expected in programs in production and early deployment.

The F-4 is a fighter/interceptor produced by McDonnell Douglas for the U.S. Navy and Air Force and for numerous other countries. In all, about 5000 F-4s have been manufactured since production began in the early 1960s. The A-7 is an attack aircraft also used by both the Navy and the Air Force. About 1500 aircraft have been produced by LTV Aerospace, the prime contractor. Production of the Air Force version (A-7D) ended in 1976. The F-111 is a multimission variable-geometry aircraft developed and produced by General Dynamics. Production of the F-111 ended with slightly more than 500 aircraft having been built. Original plans called for 1700 F-111s, but the quantity was reduced when the program encountered severe financial and technological problems. Finally, the C-5 is the Air Force's heavy lift jet transport produced by Lockheed. It is often cited as a prime

example of the failure of the Total Package Procurement Concept.* Eighty-one C-5s were originally produced (about half of the planned buy), and 78 remain in the inventory. Although the C-5 is currently out of production, a major retrofit effort to correct deficiencies in the fatigue life of the wing is planned to begin at the end of the 1970s.

SPECIFIC SUBCONTRACTOR PROBLEMS

As described in Section II of R-2184/1-AF, the two problem indicators about which our aircraft survey yielded data are (1) whether or not capable alternative suppliers were available during programs, and (2) whether prices were excessive, suggesting insufficient competition.

We will take up each of these indicators in turn, and will then consider other problems that surfaced in the course of our survey, but which do not fit neatly into either of these categories.

Necessity to Change Suppliers

Bankruptcies. The original manufacturer of the gun mount for the GAU-8, the primary A-10 armament, went bankrupt. In the SPO's perception, this bankruptcy was related to general economic conditions at the time when it occurred. Another supplier was available.

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*This concept involves getting a commitment from a contractor for both development and production of a new weapon system while there is still a real competitive environment. A successful use of this technique is described in the discussion of the Maverick program in Appendix B. For a discussion of the concept itself, see T. K. Glennan, Jr., Innovation and Product Quality Under the Total Package Procurement Concept, The Rand Corporation, RM-5097-PR, September 1966.

Because of the extensive redesign of the C-5, and other problems of a more generalized sort that arose in its development and production, there were a number of bankruptcies among the subcontractors and suppliers that participated in the program. Indeed, until Congress approved a $250 million loan guarantee, the continued participation of the prime contractor (Lockheed) in the industrial base was at risk. Despite these problems, the airplanes finally ordered by the Air Force were produced, and Lockheed appears to have access to adequate subcontractor and supplier support for the rewinging effort that is planned. For the C-5 program, delivery of the aircraft was a limited success indeed! But there is no evidence available to us that there were any problems with the lower-tier firms or that reticence on the part of these firms caused the problems that did occur.

<u>Change in Corporate Structure</u>. Conair Corporation was a supplier of metal flaps and some other metal fabrication for the F-15. Conair was acquired by another firm that decided to abrogate all of its military contracts. In response to this problem, McDonnell Douglas sent the Chief of Purchasing to negotiate the purchase of tooling, drawings, and the work in process that related to the F-15, and then set up McDonnell Douglas in Long Beach to take this work in-house. (McDonnell Douglas' takeover included the purchase of Conair's jigs and fixtures, as well as goods in process to be transferred to the Douglas facility.) The Air Force reimbursed McDonnell Douglas for 85 percent of the cost involved in this process, according to the cost-sharing arrangement in the contract. The main objective of taking this work in-house was to prevent the schedule from being delayed. A lower-overhead operation for the production than the

Douglas plant offered would have been desirable, but the schedule was the paramount concern.

Supplier Dropped Product Line. There are five major subsystems in the gun for the A-10. Of those five, the ammunition drum is the most intricate, and its most intricate subcomponent is the inner helix. The original source of the inner helix was Hughes-Treitler. The firm indicated that it planned to drop this product line and was no longer interested in producing this component for GE. Although GE was able to find an alternative supplier (Aerosmith), it has had more problems with the component since Hughes-Treitler, a very capable precision machining firm, dropped out of the business. Because of these continuing problems, GE has considered developing an in-house backup capability for producing the inner helix.

EPA, OSHA, EEOC, etc. One problem faced by the Air Force in connection with the C-5 involved a laminated material used in the interior of the aircraft. The original producer supplied a sufficient number of sheets of this material for a production run of the aircraft and some extra sheets as well. Then EPA and OSHA requirements imposed on this contractor necessitated an investment of approximately $150,000 to $250,000 in replacement machinery. In order to make the necessary changes in its operation to meet these standards, the company decided it must have assurances from the Air Force on the volume of business--in the form of a 2-year order for 10,000 sheets of the material as opposed to the usual incremental requests for 300 to 400 sheets. The Air Force took steps to pool requirements and establish an order for one purchase. However, in the meantime, the engineers at the firm discovered a new process that minimized the requirement for new

investment. In light of these developments, the supplier decided to continue in the business.

During the development and early production stages of the armament and engine for the A-10, GE lost some of its castings and forgings suppliers because they failed to comply with EPA or OSHA standards. GE was able to find alternative sources, however, and, as a hedge against the consequences of further unavailability of initially selected sources, the company has resorted to an increased amount of dual sourcing.

Debarment proceedings--i.e., proceedings to exclude a firm from participation in government business--based on failure to comply with Equal Employment Opportunity Commission requirements were instituted against Timkin Roller Bearing, one of GE's suppliers in the A-10 engine program, thus creating a situation in which GE would have to find a substitute supplier. However, since Timkin was in the position of being the sole source, the debarment was not effective with regard to its participation in the A-10 engine program, and was ultimately rescinded.*

Declining Demand. An additional problem for the DoD's suppliers or prime contractors is the unpredictability and low volume of demand for specialized products. In some cases, in which an option is available, these two characteristics have encouraged suppliers to get

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*The debarment ruling was recently reversed in a district court decision that found it reasonable for Timkin to limit its affirmative action recruitment program to a 15-mile radius of its plant rather than to expand the recruitment area to include another city that had a larger population of minorities. See "Equal Opportunity: Justice Department Decides To Drop EEO Debarment Case Against Timkin," Federal Contracts Report, No. 668, February 14, 1977, p. A-3.

out of defense business altogether, as in the case of a former castings supplier in the A-10 engine program that now manufactures castings exclusively for golf clubs. In another case, since its Air Force contracts did not constitute a significant share of its total business, a castings supplier for the armament refused to make a process change in a gating technique to meet Air Force specifications. Despite these problems, GE has been able to find alternative suppliers for these castings.

In the A-7 program, the original supplier of a type of square wire used in the generator stopped producing the wire because the demand for it was solely military and very limited. The generator was redesigned to accommodate round wire, and an alternative supplier was found.

Possible Consequences of Foreign Dependence. Given that our European partners are producing 10 percent of the procurement value of U.S. Air Force F-16 aircraft, an important issue is the extent to which we might be vulnerable if one of the European subcontractors became unwilling, once production was underway, to supply the expected product. It would appear that this situation would not pose much of a threat to the U.S. portion of the program, since, with the exception of the Head Up Display (HUD), which is being produced only by a British firm (Marconi-Elliot)--not part of the European consortium in any case--all the subsystems and components have U.S. as well as European suppliers.

Excessive Prices

The original manufacturer of the photoflash ejector system for

the reconnaissance version of the F-4 stopped producing the ejector and sold its data rights to a second firm. That firm, in turn, sold those data rights to a third firm, which resumed production of the ejector system and spares. This new source of supply raised the price of the system by a factor of 2 to 3 and raised the prices of some of the spares by as much as a factor of 10. Because there is an ongoing demand for these systems for the RF-4, and particularly for the spares, the Air Force is <u>purchasing</u> the data rights so that it can reintroduce competition into future reprocurement. It is important to note, however, that obtaining the data rights for this photoflash ejector system at this point does not avoid the costs of dealing with a monopolized source of supply. To prevent this situation, provision for data rights must be made at the outset of the program.*

In Section III of R-2184/1-AF, we indicated that much of our information on excessive prices had been obtained indirectly from data on the price reductions yielded by reintroduction of competition, in many cases by means of using dual sources for a product.

In an effort to avoid a situation in which excessive prices might be charged, and to distribute the business more widely, the A-10 program office is attempting to bring Bendix on board as a second source for the landing gear by the time that the 59th aircraft is in production (the early part of calendar 1978). Menasco is the original source. This effort is being undertaken partly for reasons that are

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*One technique for precluding a lock-in position because of data rights is known as directed licensing. For an extensive evaluation of this technique, see G. A. Carter, <u>Directed Licensing: An Evaluation of a Proposed Technique for Reducing the Procurement Cost of Aircraft</u>, The Rand Corporation, R-1604-PR, December 1974.

specific to the A-10 program, particularly because of the potential attractiveness of having two sources and being able to use price competition in the procurement of the landing gear. It is also being undertaken because there are very few landing gear suppliers for military aircraft; Menasco clearly is the dominant firm in this field. Obtaining Bendix as a second source for the A-10 would help to preserve a broader base of suppliers for this mechanism.

Other Supplier Problems

Technological Difficulties. Another potential supplier problem relates to the state-of-the-art development of the cockpit enclosure for the F-16. Texstar, Inc., won a firm-fixed-price contract to design and build a cockpit canopy formed from monolithic polycarbonate, a material that has recently been introduced into the manufacture of cockpit enclosures for high-speed, low-flying aircraft because it is highly fracture resistant.* However, the polycarbonate material is vulnerable to pitting and erosion from rain, dust, etc., and must be covered with a special coating to protect the canopy and maintain unimpaired visibility for the crew. Texstar won the contract for the F-16 cockpit enclosure on the strength of its claim to have made a breakthrough in the development of a suitable coating. So far, however,

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*Fracture resistance is necessary because of the possibility of bird strikes to the cockpit enclosures of aircraft (like the B-1) that operate at high speeds and low altitudes to avoid radar detection. Similar problems for fighter aircraft are encountered mainly during climb and descent. For a detailed discussion of the technology involved, see "Cockpit Enclosures Performance Key," Aviation Week and Space Technology, January 26, 1976, pp. 89-93.

technological problems have caused the canopies to have a much shorter Mean Time Between Failure (MTBF) than planned. The development effort is continuing.*

<u>Lead Time for Parts</u>. Problems have also occurred in the radar warning system for the F-15. The Loral Corporation is the prime for this system,** and Watkins-Johnson is a supplier of low-frequency YIGS (Yttrium Iron Garnets). The problem here was mainly the long lead times required to produce high-reliability parts for the YIGS. However, the system has been produced despite initial problems.

<u>Low and Declining Demand</u>. One of the problems mentioned by the F-15 SPO has as its major element the administrative difficulty of going from design to production of an electronics "black box." Magnavox designed the electronic warfare warning system, which was a difficult task because of the rigorous requirements for miniaturization. The design required the use of some parts that had to be supplied by foreign sources because the several domestic suppliers (nine to be exact) of these parts, which were approved on the Qualified Parts List, had either gone out of business or refused to bid. The reason most commonly stated for the firms' lack of interest was the low-volume purchases of items such as resistors, integrated circuits, and specialized transistors. When the production phase was reached, the drawings needed to be "cleaned up" prior to beginning production,

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*For a more detailed discussion of the industry that produces cockpit enclosures for aircraft (and the history of Texstar's participation in this industry), see Section IV in R-2184/1-AF.

**Loral has a direct contractual relationship with the Air Force, which then furnishes the subsystem to McDonnell Douglas as Government Furnished Equipment.

and an attempt was made to go back to the Qualified Parts List to replace the foreign-made parts. But some of the domestic suppliers were just not available, and the foreign purchases had to be continued.

Another problem that occurred in the production of the F-15 involved the low profitability to one of the key producers. The Curtiss-Wright Corporation has a number of divisions, including machining divisions important to the McDonnell F-15 operation. The machining operations needed additional investment capital that the parent corporation was unwilling to supply because the volume of business was low and the operations were not very profitable. The machining divisions requested GOCO (government-owned, contractor-operated) equipment as an alternative to their possibly getting out of this line of business. Some government-owned equipment (numerically and manually controlled machines) was provided under the Plant Equipment Package (PEP) program on the theory that the continued participation of these machining operations in the industrial base was vital not only to the F-15, but to future Air Force programs as well.

Obtaining ammunition for the A-10 gun has also posed problems. Ammunition manufacturers are reticent about making capital investments in needed facilities and equipment. They are reluctant to commit their own funds because of uncertainty over total demand and rate of demand, so they want the government to fund needed investments. Aerojet Ordnance and Minneapolis Honeywell were cited as two of the firms associated with this problem. The government, through the Defense Industrial Plant Equipment Center (DIPEC), has provided some equipment (so far mostly surplus equipment). The problem is

compounded because the buyers of ammunition prefer to use dual sourcing. The use of two sources would presumably give rise to more requests for government plant and equipment than would a single source. On the other hand, not maintaining two sources might lead to a situation in which only one source (with limited production capacity) was available, no matter how large the need for new production.

ANALYSIS OF SUBCONTRACTING

Overall, subcontracting problems (i.e., unavailability of initial suppliers, difficulty in obtaining alternative suppliers if firms cease participation, etc.) do not appear to have posed serious threats to any of these programs. In the case of the F-15, for example, where problems have occurred, the prime contractor has acted swiftly and decisively to remedy them (as in the Conair case discussed above).

McDonnell Douglas seems (as confirmed in our interviews at the SPO) to have tried as much as possible to minimize risk by selecting relatively large, financially sound firms as initial subcontractors. Although this approach does not guarantee the absence of problems (and, in fact, may lead to some special ones as indicated by the Garrett-McDonnell litigation), it does lessen the possibility that subcontractors might falter or even go out of business if they encounter unforeseen difficulties in the course of a program. When smaller, less financially viable firms were chosen (usually because of some technological capability), these firms were subject to special monitoring by the prime contractor so that any difficulties that occurred could be diagnosed and corrected before they became serious. Because the F-15 is a very high priority Air Force program, considerable

resources and effort have been directed toward minimizing the effects of any problems, whether subcontractor related or not.

Subcontractor problems experienced by the A-10 prime contractors (and here our information pertains mostly to the armament and engine) do include some of the things believed to be causing erosion of the industrial base: bankruptcy, adverse effects of EPA and OSHA regulations, etc. However, for those cases in which participating firms have dropped out of the program, alternatives were available and action has been taken. Furthermore, one of the prime contractors (in this case, GE) has on occasion taken special actions to assist its subcontractors, such as helping the manufacturer of the gun barrel to obtain steel during a period of shortage in the early 1970s. All in all, the difficulties that have been encountered by the A-10 program as a whole (such as failure to meet performance requirements and consequent delays) appear to have resulted more from Fairchild-Republic's lack of recent experience as an airframe manufacturer and system integrator than from any subcontractor and supplier troubles.*

With regard to the F-16 program, it is really too soon to know what impact subcontractor and supplier problems will have. What we do know is that any possible erosion of the base does not appear significant enough to have interfered with the Air Force's and General Dynamics' ability to find U.S. participants for the program. As far as the European firms are concerned, any problems with initial recruitment seem to be the result of uncertainty over whether the

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*See also, for example, "A-10 Program Approach Reshaped," Aviation Week and Space Technology, February 10, 1975, p. 45.

potential European firms are technologically competent and reasonably price-competitive with U.S. counterparts rather than firms' unwillingness to become involved. Finally, the fact that virtually all components manufactured in Europe will also have U.S. suppliers should allay any fears about our potential vulnerability to total loss of supply should a foreign supplier drop out.

The major problems encountered with aircraft that have been in the inventory for some time and are out of production (C-5, A-7, F-111, F-4) seem to be caused by firms' reluctance to get involved in very low volume business. When the volume of business is larger, either because of demand for products for a single weapon system or for products used in more than one aircraft, the industrial base seems to meet the military's needs. Isolated examples of excessive prices, such as those for the F-4 photoflash ejector, appear to result more from initial contracting practices that limit competition rather than from a lack of available firms.

Finally, our tentative conclusion that the lower tiers of the industrial base supporting these seven programs have not been characterized by serious erosion is not in conflict with the obvious fact that several of these programs have been plagued by serious problems of cost overruns, performance shortfalls, and/or schedule slippage. What our research (and considerable past research at Rand and elsewhere) suggests is that problems such as those encountered in the C-5 program, for example, are a consequence of more pervasive flaws in policy relating to major systems acquisition, and are not due in any major way to a lack of support from the lower tiers of industry.

FINAL OBSERVATIONS ON THE AIRCRAFT SURVEY

Our final comments on the results of the aircraft survey have to do with the current state of the market for defense-related products. Our contacts with the aircraft program offices did reveal cases in which subcontractors had had problems during programs (or had even left the industrial base entirely) because of some of the purportedly perverse characteristics of defense business. But the major thrust of most of our survey information had to do with the low volume and erratic nature of the DoD's demand for products. In the post-Vietnam era of changing priorities for government spending, outlays for procurement of military systems have declined in real terms. Furthermore, increasingly high unit prices for technologically sophisticated systems have led to reductions in the total number of units purchased. Thus, there has simply been less defense business available in the recent past. When what business there is involves a small total quantity for which the rate of demand is uncertain--either because of the unpredictability of decisions on year-by-year appropriations for new systems or because the total buy or requirement for logistics support is unpredictable--it is understandable that firms either (a) avoid defense business if alternatives are available, or (b) accept defense business but are unable or unwilling to make potentially cost-reducing investments.

The first type of response is particularly likely to occur in industries, such as electronics components, whose commercial business is growing. According to officials in the aircraft program offices, problems arise because demands made on the industry by the military

tend to be for relatively small quantities of very specialized products, which usually have different technological characteristics than their commercial counterparts. Moreover, their producers must operate within the administrative framework that governs military contracting. When electronics firms have the alternative of large-volume commercial business, they are reluctant to interrupt their production runs to accommodate the military's requirements for small numbers of specialized products. The result, according to one SPO, is that suppliers must be enticed into accepting military business by "a lot of flag waving," and still the military ends up paying very high prices. Possible remedies for this problem might include aggregating what military demand there is and/or making more use of commercial substitutes.*

The second type of response--undertaking limited defense business but avoiding any new investment--can cause reduced efficiency and increased prices. In extreme cases, it may even lead to the loss of a source of supply as, for example, when a firm does not comply with EPA requirements for changing its equipment. Some of the problem cases described above are clearly due to confusion over the government's policy with regard to ensuring that adequate facilities and equipment are available for producing military weapon systems. For several years, it has been official policy (though only partially implemented) to phase out government-owned plants and equipment. Contractors have argued, however, that low volume and low profitability of defense

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* For more discussion of these alternatives, see Sections III and V in R-2184/1-AF.

business, combined with adverse Internal Revenue Service rules on depreciation and nonallowability of interest costs, are a disincentive to investment in new equipment. The government's response to this argument is to provide progress payments to contractors (which often flow down to subcontractors). It has also established some special programs, such as PEP, under which it provides large quantities of government-owned equipment. All in all, however, none of the policy initiatives taken recently appears to have been very effective in changing the situation,* and official policy remains contradictory and confusing.

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*See Section V in R-2184/1-AF for a discussion of the effects of DoD's most recent profit policy.

Appendix B

MAVERICK

PROGRAM OVERVIEW

Maverick (AGM-65) in its original version is an electro-optically (E-O) guided air-to-ground missile (A and B versions) for use against tanks and other hard-surface targets. In 1968, after 2 years of intensive competition, Hughes Aircraft was awarded the prime contract for Maverick. At present, the second contract for a buy of 6000 E-O Mavericks is now being executed after an initial buy of 17,000. A laser-guided version of Maverick (C version) is in early development (with Rockwell International having overall responsibility for development of the laser seeker and Hughes as system integrator). An imaging infrared seeker (IIR) Maverick is also in development at Hughes.

The first Maverick contract was a total package procurement--a fixed-price-incentive contract (70/30 share ratio, 125 percent ceiling) covering the development of the missile and options for the purchase of as many as 17,000 missiles. The contract contained various options for purchases of missiles up to this total number. The options could be exercised as follows:

Method I	Method II	Method III
17,000	2,000	2,000
	5,000	5,000[a]
	10,000	10,000[b]
	17,000	17,000

[a]Could be exercised for increments of 1000.

[b]Could be exercised for increments of 2000 or more.

The contract also contained an economic escalation clause which provided that the contract price would be adjusted to reflect "abnormal" increases or decreases in the prices of labor, materials, etc. The adjustment determination was made according to an established formula that used a mix of Bureau of Labor Statistics indexes.

Another important feature of the original Maverick contract was a value engineering clause under which the contractor was able to trade off extremes of performance that weren't worth their cost. The existence of the ceiling price made this flexibility very useful.

At the outset, Hughes expected that the Air Force would probably not buy more than 9000 to 11,000 of the possible 17,000. The Air Force did, in fact, buy all 17,000 according to Method III. The 5000 missile option was exercised in increments of 2000 and 3000, and the 10,000 missile option was exercised in increments of 4000 and 6000. The highest production rate attained was about 1000 missiles per month, and the average unit price was approximately $13,000 to $14,000.* Buys under the total package procurement contract ended with Hughes producing the missiles at approximately the target costs, and, according to officials of the Maverick System Program Office, Hughes made a profit of about 8 percent on sales. The Maverick program is frequently cited as the only successful example of the use of total package procurement.

The current E-O Maverick contract is firm-fixed price for a buy of 6000 missiles at a production rate of 400 per month and a price of

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*Given that the Air Force bought almost 50 percent more missiles than Hughes anticipated, the production rate was obviously much higher than had been planned for, and it is 2.5 times the rate planned for the first follow-on buy.

approximately $18,000 per unit in then-year dollars. Still another follow-on contract of electro-optically guided Mavericks, at a production rate of 200 per month, has been set up.

OVERVIEW OF SUBCONTRACTING

As was the case for the prime contract, there was vigorous competition among potential subcontractors for the Maverick program. Hughes was able to select from a good group of potential participants. Of those not initially selected, there were several firms that indicated that they would continue to be interested during the life of the program. In at least one instance, such a firm became an alternative source when an initial choice had to be replaced.

Two features of the environment within which the Maverick subcontracts were negotiated are of particular importance. First, the total package nature of the prime contract made it important for Hughes to "drive hard bargains" with its subcontractors and to be fairly confident that the firms could perform within the limits of those contracts. Second, the long-term, firm-fixed-price contracts, which had to be performed during a period in which an unanticipated high rate of inflation prevailed, had a definite effect on the subcontractors accepting them. The economic escalation clause that Hughes received from the Air Force was offered to the subcontractors. According to Hughes, most of the potential subs were not inclined to accept the clause because of confidence in their ability to price their contracts in such a way as to allow for fluctuations in the cost of labor, materials, etc., and because of their unfamiliarity with this type of clause. It is also worth noting, however, that the offer

of the abnormal economic escalation clause was made in a competitive environment, and those firms that were willing to accept the terms (and risks) of a straight fixed-price contract might have an advantage in the competition.

There were 60 first-tier subcontractors involved in the Maverick program and approximately 100 other firms. Approximately 85 percent (in terms of cost) of the subcontracted items were controlled within the program, and the other 15 percent were handled by Hughes' general purchasing group. Thirty-six technically critical items were singled out for day-to-day monitoring; the composition of this group of 36 critical items varied during the program. In general, Hughes exerted considerable surveillance and management control over its subcontractors, presumably at least partly because of the pressure created by the total-package contract. Hughes zealously guards its position as the party with legal responsibility for and authority over its subcontractors.* Maverick program officials also expressed the view that many firms preferred to be subcontractors rather than prime contractors so that they could be in a position of having a "buffer" between themselves and the government buyer.

SPECIFIC SUBCONTRACTING PROBLEMS

During the course of the first Maverick contract, various subcontractor and supplier problems did occur. What these difficulties

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*For example, Hughes officials (supported by the Maverick System Program Office) would agree to assist Rand in making contact with Maverick subcontractors only if Hughes personnel were allowed to be a party to the interviews that occurred.

were and how they were dealt with by Hughes and/or the SPO are summarized below.

Necessity To Change Suppliers

Bankruptcies. Guidance Technology, Inc., was initially selected by Hughes to develop and produce the gyroscope motor assembly and the torque assembly, at least partly as a result of a favorable experience Hughes had had with the firm during a competition for the Walleye missile in 1965-66. The selection was also made despite the fact that Guidance Technology had once previously been in and out of a bankruptcy proceeding. During the development program, Guidance Technology had both technological and financial problems, and it once again petitioned for reorganization under Chapter 11 of the Federal Bankruptcy Act.

Hughes needed alternative sources for both components. For the torque assembly, it first utilized in-house capability and then signed a contract with Globe, a division of TRW. Globe was one of the firms that, not having initially been selected as a Maverick subcontractor, had periodically expressed interest in getting into the program should an appropriate opportunity arise.

For a while, Hughes also utilized its in-house capability for the gyroscope motor assembly but had its own technological problems. Clifton Precision Products, a division of Litton Industries, was finally persuaded by Hughes to produce the assembly.

In this case, a subcontractor's financial difficulties caused problems for the prime contractor. However, Hughes was able to find alternative sources for both components and to proceed with the program. As a final note to this episode, Guidance Technology has

recovered from its financial troubles and is once again trying to get business from Hughes.

Another bankruptcy occurred when the original source of the missile shipping container, Nash Hammond, dropped out of the program. Although the company's basic financial and managerial problems were not directly traceable to its participation in the Maverick program, there were some difficulties and changes associated with the initial development and production of the container. The original idea was that Nash Hammond would produce an environmentally controlled plastic container so that the missile itself would not have to have an airtight seal. However, it ultimately became clear that it would be easier and cheaper (in terms of overall program cost) to hermetically seal the missile guidance unit than to try to produce an environmentally controlled container. After Nash Hammond ceased to participate in the program, two sources, Ametek-Straza and Champion Company, were brought in as suppliers of a metal shipping container for Maverick. For each buy, competitive bids were obtained from both sources, and the containers were purchased from the lower-priced source. This case provides indirect evidence that a potential for high prices can exist in situations where purchases are being made from a sole source.

Subsequently, the Maverick program office "broke out" the shipping container from the prime contractor's procurement system and sponsored a small-business set-aside competition among six firms for a new, lighter-weight plastic container. For logistics reasons, the SPO wished to convert to a plastic container, and it chose Plastics Research Corporation to manufacture the new container.

Design Dispute. During the development phase of the Maverick, Hughes changed suppliers for the missile warhead. FMC, the original supplier, and Hughes had had disagreements over what kinds of metals to use in various parts of the warhead. In Hughes' view, incorrect choices of metals made by FMC had caused difficulties in the development program. Once Hughes brought Chamberlain Manufacturing Company into the program as the alternative supplier of the warhead, the development and production proceeded smoothly.

EPA, OSHA, and Natural Causes. Difficulties with the thermal battery production for the Maverick involved the critical chemical compounds used in these batteries. Between 1972 and 1974, Eagle-Picher and the other firms in the specialized-battery industry lost their sources of supply for zirconium powder, calcium chromate, and barium chromate. The loss of the supplier of zirconium powder occurred when the Foote Mineral Company had a fire in its production facility; Foote was the only source of zirconium powder manufactured to the rigorous specifications for use in missile batteries. When the Foote Mineral facility burned, Ventron became the alternative source, but it has had technological difficulties in producing the powder. The continuing uncertainty over the availability of adequate supplies of zirconium powder from single sources has caused the Air Force Materials Lab to contract with two firms to investigate alternative production processes and to establish a clearer definition of what characteristics the powder must have. Depending on the outcome of this investigation, a captive production line* may be set up.

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*This is a production facility owned and committed to production for DoD requirements (although the facility may very well be contractor operated).

Eagle-Picher and its suppliers have also had difficulty in obtaining adequate quantities of barium chromate and calcium chromate, two other chemical compounds necessary for thermal battery production. The original supplier of barium chromate left the business because of both low profits and the burdens of complying with Environmental Protection Agency requirements. An alternative supplier was found, but quality control has been a problem for the new supplier.

Allied Chemical, Eagle-Picher's supplier of calcium chromate, decided to stop manufacturing the material when the Occupational Safety and Health Administration ruled that its production facilities did not meet OSHA's requirements. Faced with the prospect of a $100,000 to $150,000 investment to bring its facilities into compliance, Allied offered to license Eagle-Picher to manufacture calcium chromate using Allied's processes. Instead, Eagle-Picher opted to establish a new source of supply, and it has assisted ReeCo Chemical Company, a small business operation, to get into production.*

During the period in which the chemical shortages were occurring, prices of the compounds rose substantially, sometimes as much as 400 percent. However, despite the various delays and interruptions in supply that Eagle-Picher had to cope with, it had sufficient stocks on hand so that battery deliveries to Hughes were not interrupted.

Also, in order to ensure that it could meet high-rate production requirements, Hughes tried to qualify a second source (Eagle-Picher being the initial source) for the thermal battery during the production

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*Summary Report Concerning Chemicals Essential for Thermal Battery Production, Eagle-Picher Industries, Inc. (Electronics Division), August 22, 1974.

phase of the program. Because of the time pressure and the technological difficulties involved in thermal battery development and production, neither of the possible second sources, KDI or Eureka-Williams, was able to qualify. Eagle-Picher, however, did deliver the batteries as required to sustain the high-production rate.

Other Supplier Problems

Technological Difficulties. The vidicon is the television camera tube for the E-O Maverick guidance system. At the outset of the program, Hughes made a management decision to dual source the vidicon. This was the only subsystem or component of the missile for which dual sourcing was initially chosen as the preferred development and procurement strategy. Otherwise, Hughes management generally believed that it could not take the financial risk of making extensive investment in dual sourcing during the development program. In the case of the vidicon, one of the potential sources, International Telephone and Telegraph, had technological problems, so its competitor, General Electric, became the single source of supply for the vidicon. GE did produce the vidicon throughout the first contract and was able to sustain the requirements for high-rate production. What is not known is whether the price of this component would have been less if ITT had also produced it and the competition had continued; however ITT's technological difficulties prevented a continuance of this competition.

Supplier Sustains Financial Loss. National Waterlift Company was the supplier of the hydraulic actuator system. During the first Maverick contract, it is estimated that National Waterlift lost $2.5 to $3 million. These losses were caused by unanticipated technological

problems that occurred within the framework of the fixed-price, total-package contract. Despite its financial losses, National Waterlift did produce the system, and it is continuing as a subcontractor on the Maverick program for the second contract at a price about 40 percent higher than that of the first contract.

Financial Loss and Competition. Thiokol was the original source for the rocket motor. The company had difficulty sustaining the high-rate production requirements, and a number of motors were rejected. These problems caused what Hughes estimates to have been a loss of $2 to $3 million by Thiokol on their $25 million contract.* Thiokol's price for the next buy of Maverick motors was expected to be about 40 percent higher than that of the first contract.

The SPO, however, decided to consider introducing competition into the procurement of Maverick rocket motors, and it is attempting to qualify Aerojet as a second source for the rocket motor. The commencement of the qualification process caused Thiokol to make a token price reduction, and, in the expectation that further savings can be achieved, the SPO may "break out" the rocket motor and procure it directly if Aerojet's qualification attempt is successful. Motors may then be procured from both sources, the larger volume being purchased from the lower-priced source.

Changes in Corporate Structure. The supplier of the rate sensor package, a very complex system, was a small division of American Chain and Cable. During the first Maverick contract, this division experienced several changes in management structure that began when the

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*It is not clear from the available information whether this was a real loss in the sense of costs exceeding contract prices, or (at least partially) a reduction in profit.

manager of the division bought it out. Subsequently, it was acquired by a larger corporation, sold back to the original manager, and finally acquired by Hamilton Standard. The consequence of these changes for the program was that at various times, when the division was operating independently, it had such severe financial difficulties that Hughes met the payroll in order to ensure continued deliveries of the rate sensor package. However, throughout all the corporate structure changes, the quality of the product remained high.

This example demonstrates first of all that one of the hypothesized causes of possible problems in the defense industrial base (changes in management structure of a subcontractor) can cause difficulties during the course of a program. It also demonstrates that prime contractors can and do take extraordinary action (in this case meeting the subcontractor's payroll) in order to avoid program disruption.

Foreign Sources for Castings. During the Maverick program, Hughes tried to use foreign sources for castings. It entered into some purchase orders with possible Australian sources, but the sources could not meet Hughes' requirements, and domestic alternatives had to be maintained as well.

ANALYSIS OF SUBCONTRACTING

As the preceding section suggests, various subcontractor and supplier problems have occurred in the Maverick program. It should also be obvious from the discussion that whereas some of the situations documented did cause real difficulties for the prime contractor, others (e.g., the inability of ITT to qualify as a second

source for the vidicon) are more accurately described as deviations from Hughes' preferred course of action rather than real problems.

Several things should be kept in mind as we attempt to assess the impact of these problem cases on the Maverick program. First, the nine cases cited involved only about 15 percent of the major first-tier subcontractors and suppliers that participated in the program, as well as a few second- and third-tier firms. Second, many of the subsystems and components involved were among the most technologically complex elements of the missile. The vidicon, thermal battery, and gyroscope motor assembly are examples of such items. Since there is a considerable amount of evidence (derived from investigations at the prime contractor level) that developing and producing technologically complex weapon systems usually leads to difficulties, such as delays and increased costs, the fact that similar difficulties occur at the subcontractor level is not surprising.* In fact, one might be more surprised if no problems arose.

The risks to the program of firms encountering technological problems were increased during the first Maverick contract by a number of circumstances that characterized the prime contract itself and the period during which it was performed. We have already indicated that the contract between Hughes and the Air Force was a total-package procurement in which Hughes promised to deliver missiles for a certain price before development had even begun. Other experience with this contracting technique (e.g., the C-5A cargo transport and the F-14 fighter aircraft) suggests the difficulty of making production

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*See, for example, Robert L. Perry et al., System Acquisition Strategies, The Rand Corporation, R-733-PR/ARPA, June 1971.

price commitments before development and the serious consequences that can occur as a result.* Although it is probably true that developing and producing a new precision-guided, air-to-ground missile is, overall, a less risky operation than developing and producing a new aircraft, many of the total-package features that caused nightmares in the C-5 and F-14 programs were present in the Maverick as well.

First, there was (as in most programs) severe pressure on the prime contractor to promise a low production price in order to increase his chances of winning the contract award. This pressure flowed down through the tiers to the subcontractors and suppliers and resulted (as our Hughes interviews confirmed) in vigorous competition among potential subcontractors. The final result was a set of contractual commitments (firm-fixed price for most of the subcontractors and a target price with a firm ceiling 25 percent above that target for the prime contractor) that most certainly did not provide the firms with great financial flexibility for dealing with technological difficulties as they arose. Compounding this basic lack of flexibility for the subcontractors and suppliers were the unanticipated high rates of inflation and other general economic conditions that occurred during the life of the contract.

This is not to suggest that either Hughes or its subcontractors were unalterably constrained by the terms originally inserted in their respective contracts. Changes in scope might be used to mitigate the effects of unusual or unanticipated events, regardless

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*For a discussion of the concept of total-package procurement and its pitfalls, see J. Ronald Fox, Arming America, Cambridge, Harvard University Press, 1974, pp. 243-247.

of their cause. Furthermore, there is evidence that firms may be recovering from the effects of their total-package commitments by their pricing policies in follow-on buys of Maverick.* Finally, the prime contract and a few of the subcontracts did have the provision for adjustments in the event of "abnormal" economic conditions.

However, even when we consider the mitigating factors, such as abnormal economic escalation clauses present in some of the contracts, it seems reasonable to conclude that the degree of risk present in the program was substantial. Given that technological difficulties are inherent in the development of new weapon systems, and that the financial arrangements in the Maverick total-package contract gave the firms only limited flexibility for dealing with them, the occurrence of some problems was predictable. Furthermore, the consequences of these problems were bearable in that they did not interrupt the delivery of missiles, even when the delivery schedule was accelerated to meet Air Force requirements for the entire quantity of 17,000. However, although the technological problems that prevented qualification of second sources within the available time did not impair Hughes' ability to meet high-rate production requirements, they may have deprived Hughes (and the Air Force) of the lower prices that often seem to result from second sourcing.**

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*For example, Eagle-Picher's price for thermal batteries varied from 92 to 98 (current year) dollars during the first contract. Its price for the 6000 follow-on batteries is 192 (current year) dollars.

**For a general discussion of the role of competition in reducing prices in military procurement, see Carter, op. cit., pp. 1-5, 62-67, and 119-123.

To summarize our discussion of technological uncertainty as a cause of lower-tier problems in the Maverick program, we can say that nearly every one of the cases cited in this appendix involved some degree of technological difficulty. The consequences of these problems for the prime contractor included failure to qualify a second source when two had been considered desirable, necessity to change suppliers during the course of the program, etc. For the subcontractors, the consequences ranged from lower-than-anticipated profit (or actual loss) on a contract to at least a partial cause of a firm's going bankrupt. The consequences for the program were not severe; despite the problems that occurred, Hughes delivered the missiles on schedule and completed the contract below the ceiling price.

Besides these general technological problems, there were also some other, more unusual difficulties associated with first-tier suppliers in the Maverick program. As discussed earlier in this appendix, Eagle-Picher, the supplier of the thermal battery, experienced difficulty in obtaining the specialized chemical compounds it needed to produce the battery. In general, the problems derived from the fact that manufacture of the chemical compounds used in pyrotechnic heat sources for thermal batteries is a very exacting and possibly dangerous process. Since the quantities of these materials required for military use are small (and there is no commercial demand for them), supplier firms have not seen fit to make the investments necessary to refine the production processes or to bring their operations into compliance with EPA and OSHA restrictions. This situation creates problems for the makers of missile batteries who have as yet been unable to find adequate substitutes for these

materials. Given these conditions (interruptions in supplies of critical, highly specialized products for which there is limited demand), the government buyer might do well to consider establishing a captive production facility. In the case of zirconium powder, the Air Force Materials Lab has taken precisely this step.

Another of Hughes' difficulties with subcontractors involved changes in corporate structure. In the case of the rate sensor package mentioned above, the several changes in the supplier's management structure during the program caused disruptions severe enough to force Hughes to take extraordinary action in order to ensure continued deliveries. However, at no time did these management changes cause the subcontractor to reverse his position about being a participant in the program, nor did they cause any real degradation in the product's quality. The important point, however, is that although problems in the defense industrial base can cause difficulties during the course of a program, they are not insurmountable, and prime contractors can and do act to avoid program disruption.

FINAL OBSERVATIONS ON THE MAVERICK

The "bottom line" result of our investigation into the Maverick program is that the subcontractor and supplier problems that did occur involved only a small percentage of the firms participating in the program, and they did not interfere with the successful completion of the first contract. Nor did they interfere with the prime contractor's ability to get an adequate (and largely identical) group of subcontractors for follow-on work. Although a few of the

lower-tier problems experienced during development and production were due to causes such as bankruptcy of firms, changing management structures, etc., by far the most pervasive cause was that of technology. Indeed, given the circumstances surrounding the award and execution of the contract (fierce competition, total-package contract performed during severe inflation, etc.), it seems remarkable that things went as well as they did throughout the program, and especially with regard to subcontracting.

Our investigation of the Maverick program has led us to some tentative conclusions about the features that contributed to its success. First of all, the relative inflexibility of the total-package contract gave Hughes, as prime contractor, an incentive to keep costs at or near target. Not only did this incentive for cost control cause Hughes to strike hard bargains with its subcontractors, it also motivated it to make certain that the subcontractors met their commitments. Moreover, the prospect of substantial follow-on buys of the E-O-guided version of the Maverick for U.S. and foreign use, plus the development of new versions of the missile using alternative guidance systems, no doubt suggested to the firms involved in the program that initial success would lead to considerable future business.

Since, in weapons acquisition, the government buyer typically plays a much larger role in the development and production of the product than does a buyer in the commercial marketplace, the buyer's

involvement in the Maverick program should be examined to determine what effect it has had on the outcome of the program thus far. In the Maverick program (as is true in other programs), the Air Force "buyer" consists of the System Program Office (SPO) and the contract administration group--the AFPRO (Air Force Plant Representative Office)--located at the Hughes plant in Tucson, Arizona, where Maverick was produced. The SPO has primary responsibility for management of the program. The AFPRO handles the details of contract administration and performs various general oversight functions at the plant that are not specific to a particular contract.

In the case of Maverick, the SPO seems to have operated on the theory that since a competent prime contractor was selected and given incentives for good performance, he should be allowed to manage the program with a minimum amount of day-to-day interference. One manifestation of the SPO's desire not to interfere was its recognition of the fact that the subcontractors and suppliers had contractual commitments to Hughes and not to the Air Force, so the real responsibility for managing the lower-tier firms belonged to Hughes.

In contrast to the SPO, the AFPRO representatives expressed dissatisfaction over their inability to gain more "visibility" into Hughes' management of its subcontractors. Since the outcome of the total-package contract was fairly successful, it is not clear what would have been gained had the AFPRO been given more authority in this area.*

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*Regulations that would give the military buyer greater authority over subcontract management (at least part of which would be exercised by the AFPRO) have been added to the Armed Services Procurement Regulation (ASPR). For our comments on the efficacy of these regulations, see Section V in R-2184/1-AF.

The preceding statement relative to the SPO's modus operandi is not meant to suggest that the SPO maintained a totally "hands off" policy with regard to subcontracting. Indeed, when the program's managers believed that circumstances warranted different actions from those taken previously by the prime, they took whatever steps were necessary to remedy the situation. Overall, the SPO's approach to overseeing the Maverick program (specifically, the total-package contract for the electro-optically guided version), has been one of general flexibility and a reliance on the managerial capabilities of the prime contractor. This approach is fairly unusual in recent experience, even in other total-package programs in which buyer "disengagement" was supposed to be part of the program.

Perhaps one reason for the SPO's apparent flexibility is the quasi-multiproject nature of the Maverick program. The three different guidance systems envisioned for the missile give the program management a range of choice that does not exist in most programs because there is usually _a_ product with one fairly definite set of characteristics. Since severe financial or technological problems with that one product may cause the program to be terminated, the program's managers have an incentive to closely monitor every development in an effort to prevent severe problems from occurring.*

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*A detailed analysis of what constitutes effective program management (ideal number of government managers, degree of surveillance required, etc.) is obviously beyond the scope of this report. However, other analysis has suggested that programs can be managed successfully with less government buyer intervention than is typical in American weapon system development and acquisition. See, for example, Robert L. Perry, A Dassault Dossier: Aircraft Acquisition in France, The Rand Corporation, R-1148-PR, September 1973, pp. 14-15. Some American experience also suggests that smaller government management teams, less surveillance, etc., have been features of "successful" programs in the past. For a discussion, see Perry et al., op. cit., pp. 23-27.

But if one version of the Maverick missile should experience severe and costly problems, the Air Force program managers could scrap it without undermining their own existence.

The preceding analysis of the relative success of the Maverick program to date is, of course, fairly speculative. Whatever the reasons for its success, however, one ingredient in that success was the relatively infrequent occurrence of problems with lower-tier participants in the program and the ability of the prime contractor (and occasionally the government buyer) to take effective remedial action when problems did occur.

Appendix C

SRAM

PROGRAM OVERVIEW

Fifteen hundred air-to-surface short-range attack missiles (AGM-69A) have been built by Boeing for testing and deployment to B-52 and FB-111 aircraft since program inception in 1966; production ended in 1975. The total program cost was on the order of $800 million. Early predictions had indicated that as many as 7000 to 8000 missiles would be procured (including some for use by the British). By September of 1973, both the program office and the prime contractor were still looking for ways to sustain a low production rate for continuous production instead of halting it entirely and later (possibly) restarting production for a version to be used on the next generation of bombers, the B-1s.

Originally, Boeing had undertaken the SRAM program as a total-package procurement (including the development and procurement phases). However, early difficulties led to severe cost growth, and eventually the entire program was restructured and commitments were revised under a fixed-price-incentive contract. As part of this restructuring, all production buys were to be made annually, rather than on a total program basis.*

OVERVIEW OF SUBCONTRACTING

There were 72 major suppliers (some of whom produced more than

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*See also "SRAM Starts Successful Production," Aviation Week and Space Technology, June 26, 1972, p. 136.

one item) directly managed by Boeing's SRAM project office, and over 2000 suppliers in all, including the "nuts and bolts" type of suppliers handled through Boeing's central materiel purchasing. Of those products managed on the project, only a few involved dual sources for the same item, and several of them were dropped in the course of the program. In general, the suppliers were retained on the basis of a firm-fixed-price commitment for 1 fiscal year with options for the next 4 fiscal years. A couple of the suppliers, involving relatively large amounts of the total dollars spent at the subcontractor/supplier level, had fixed-price-incentive contracts with Boeing. Lockheed Propulsion, the supplier of the rocket motor (and the largest subcontractor in terms of dollars), had a fixed-price-incentive contract until 1973, but a firm-fixed-price commitment thereafter.

The SRAM program provides useful insights into the continuity of the lower tiers of the defense industrial base. At the time of this research, it appeared that SRAM would be put back into production in a modified version for use on the B-1. SRAM-B, the follow-on procurement, was to have significant redesign of some parts of the missile, including a long-life motor, a new computer, and a new warhead. At least 550 missiles were to be procured (50 for testing purposes). Production initiation was planned for 1978, with first deliveries in 1981. There were to be as many as 2000 built, and the production decision was contingent on the decision to go ahead with the B-1.*

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*As a result of the June 1977 presidential decision against the production of the B-1, work on SRAM-B has been terminated. Development efforts related to the long-life missile motor and a test set for both SRAM and ALCM (Air Launch Cruise Missile) are continuing.

In anticipation of this possible restart of the program, Boeing conducted a study of first-tier suppliers on the original program, and found that all of the original suppliers were willing to participate in the new program, with the exception of two companies. Lockheed Propulsion had discontinued its production of rocket motors. Thiokol is developing and will produce the new rocket motor, and there were other alternatives.* Also, the supplier for the command destruct delay/relay for SRAM-A, Agastat Corporation, came back with a "no bid" for SRAM-B. However, even without Agastat, Boeing felt there was a sufficient choice of suppliers for this component to pare down the selection to one of two other highly qualified bidders. One of those, Consolidated Controls Corporation, had estimated its price for the new production at about 50 percent above Agastat's final price, an actual difference in dollars of about $100 per unit.

Boeing's study did not reveal that GE, the supplier for the rocket motor casing, might not make a commitment to be a producer in the SRAM-B program (for more on this, see the case study of this subcontractor, below). From Boeing's standpoint, GE is a second-tier supplier, not directly contractually committed to Boeing in the past production. The Boeing study did not consider subcontractors below the first-tier level of production capability.

SPECIFIC SUBCONTRACTING PROBLEMS

As in our discussion of the subcontracting problems encountered in the various aircraft and Maverick programs, we have organized the

*See also the discussion of the rocket motor industry in Section IV of R-2184/1-AF.

following discussion under three headings: "Necessity to Change Suppliers," "Excessive Prices," and "Other Supplier Problems."

Necessity to Change Suppliers

Supplier Dropped Product Line. The command destruct delay/relay mentioned above created problems for the prime contractor even during the SRAM-A program. Agastat had told Boeing in 1973 that it was going to discontinue production of these items and wanted to get out of the military business entirely. Agastat dropped this product line in FY 1974.* In order to complete the program, Boeing anticipated its FY 1974 requirements for this item and purchased the required numbers in FY 1973, even though it had not received the advanced funding to take such an action.

A filter connector was built by Anthanal for an initial production price of about $750. In December 1973, the production was discontinued because the buy was completed. It was thought that no further orders would be made, so the tooling was scrapped. By mid-1974, the Air Force decided that it needed 25 more of these filter connectors because it didn't have enough spares. The low volume of the subsequent buy made it unattractive for suppliers to bid on it; in fact, Boeing got no bids when it first attempted to find an alternative supplier. Boeing used its corporate relationship with Bendix, a high-volume supplier and therefore a "preferred supplier" of Boeing's on many of its other programs, to build the follow-on

* We attempted to ascertain the reason for this departure from the military marketplace, but the firm was indeed out of business when this research was undertaken.

filter connectors. Bendix agreed to do it for reimbursement of $27,000 for purchase of tooling and then $321 per unit for the 25 units bought (for a total cost per unit of about $1400). Bendix made this commitment in September 1974, but by July 1975 had failed to pass the thermal-shock qualification test. This failure necessitated substantial redesign and retooling.

One of the implications of this example is that the administrative cost alone in the purchase of additional spares can far exceed the price of the additional components. In the above instance, Boeing resolved the problem by assigning an engineer to assist in the qualification process, which was finally completed, and the units were delivered. The additional cost of the qualification test was to have been partially absorbed by Bendix.

<u>Acceptance Test Difficulties</u>. The command destruct receiver has involved several sources of supply.* The original supplier of this component dropped out of the program during the DT&E phase because of technological difficulties. Acctron came in and began building the receiver, but its yield was low--on the order of 25 percent of its production was satisfying the acceptance test. This lower-than-expected acceptance rate was threatening Boeing's ability to meet its overall schedule commitments for the SRAM missile. However, the acceptance tests were unusual--involving initial approval by Boeing, but ultimate approval by White Sands Missile Range (WSMR).

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*The command destruct receiver is used only for flight test, so it is a low-volume production item in any case. For further details, see the discussion entitled "The Industrial Setting," pp. 63-64, below.

The tests applied by WSMR were considered by Boeing to be very stringent and perhaps even unnecessarily restrictive. Boeing was concerned because the Air Force had not accepted its responsibility either to be involved with the acceptance test or to let Boeing do so. Instead, the Air Force delegated the authority to a third party, namely the Army (manager of the White Sands Range and the SRAM tests). Because of these difficulties and the consequent costs, Acctron wanted to get out of the program.* Boeing was able to exercise some production options with Acctron until FY 1972 for unit costs of $4155. Although Acctron had expressed a desire to withdraw from the program, it did agree to continue manufacturing the receiver, but at a substantially increased price.

Boeing found another source of supply through consultation with the test personnel at WSMR. The alternative source selected by Boeing was ARF Products, Inc. ARF manufactured the command destruct receiver and, because its personnel had worked with the people at White Sands before and were directly involved with the testing procedures, it had much less difficulty than Acctron in gaining acceptance of the product. The first buy from ARF, which was for FY 1973, was for 36 units at $2475 each. The FY 1974 buy was for 39 units at $3075 each. The cost of the tests for qualifying ARF as an alternative supplier was about $33,000. ARF had a much higher acceptance rate than Acctron, and the

*Part of the reason why Acctron withdrew from the program may have been that it was bought out by McDonnell Douglas during this period. It is possible that McDonnell Douglas decided that this was an unprofitable product line.

program proceeded without further technological problems. (For further discussion of ARF Products, see the case study of this subcontractor below.)

The problem in this case seems to have stemmed from the fact that the acceptance test criteria came as a surprise to Boeing during the course of the program. Since these criteria, and the test procedures devised by WSMR, did not directly involve the Air Force, which was Boeing's "government buyer," Boeing had to cope with the test criteria of a third party--the Army. Contracting difficulties ultimately arose because Acctron, the original supplier of the command destruct receiver, had bid on a specification devised by Boeing, which may not have been adequate for the acceptance test devised by WSMR.

Labor Problems. Another example of change in the source of supply occurred with respect to an extension ring forging. The original order, placed with Radiation International in November 1972, involved tooling costs of $18,347 and production for the first two batches, which consisted of 189 units at $397 each, and 154 units at $382 each. It was during the second production buy that problems occurred. There was a strike at the plant, and technological problems had arisen in the process of holding the part for concentric milling operations. These problems forced Boeing to produce this part in-house for a short time (even though its own machine shop was loaded) while it attempted to locate an alternative supplier. Finally, in August 1973, Boeing selected Automation, Inc. as an alternative source. Within 90 days,

Automation was in production and delivering its first parts. Whereas Boeing and Radiation International had used a single spindle mill, Automation used an entirely different production concept that required only $1985 worth of tooling in addition to a 6-spindle mill that it already had in operation.

According to Boeing, Automation had been trying to get into defense business at the time, and it "capitalized" some of its own machines to enter the market. After Boeing had finished its first 22 forgings, it turned production over to Automation, which produced 454 units at $327 per unit. Both Radiation and Boeing had been able to sustain a production operation that involved a 62-day production pipeline. By using its 6-spindle mill, Automation was able to reduce that time to 18 days.

During the early 1970s, parts machinists were in very tight supply, and Boeing had had trouble getting machinists for its own work. But conditions had reversed by the time that Automation entered defense work. Business was just picking up, and lead time for new production had lessened considerably. Boeing described the market as relatively "full demand," but not quite the "seller's market" that it had been in the earlier part of the 1970s.

Overall, this problem case shows that it is possible to lose one supplier and to change to another with no adverse effect on the schedule, and at the same time to improve the process and lower the unit price.

Excessive Prices

In the SRAM program, as in others we surveyed, data on the savings

achieved from competition leads to inferences about the excessive prices that might have been charged as a consequence of continuing to use sole-source suppliers. For example, Lockheed Propulsion Company, producer of rocket motors for the SRAM-A, won the initial competition over Thiokol and Hercules because it had the technological capability needed to produce the motor, i.e., Lockheed had developed some unique tooling and production processes. In fact, this dual-pulse rocket motor, which was very difficult to develop and produce, has been characterized by Boeing as having extended the state of the art. However, during the flight test program, Lockheed experienced difficulties that caused serious financial problems for the development program as a whole.

Under its firm-fixed-price contract with Boeing, Lockheed lost about $45 million on the development phase of the program. After ensuing litigation was settled, this loss was reduced to about $20 million.*

By FY 1971, 101 rocket motors had been delivered at a price of about $296,000 each. In FY 1972, 465 were built at a price of about $125,000 each. By that time, Boeing had done a cost analysis showing that the price of the rocket motor was too high. The Air Force also expressed an interest in finding a way to reduce the price. So Boeing was authorized to get a second source.

In FY 1973, Boeing invited Thiokol-Wasatch to qualify as a supplier. Thiokol agreed to spend its own money and, having had considerable experience in building solid fuel rocket motors in the

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*The grounds for the suit were primarily that the performance specified was beyond the state of the art existing at the time of the contract.

past, agreed to be reimbursed for the qualification expense only if it were successfully qualified. Thiokol also bid for a production of 153 rocket motors for FY 1973 at a price of just over $97,000. This, in itself, led Lockheed to bid on the remaining 327 motors needed for that fiscal year at a price of $76,340 a unit. Although Thiokol failed to pass the qualification test within the deadline of 14 months, the qualification cost of $9 million was ultimately reimbursed by the government.

Thiokol's failure to pass the qualification test was due, in part, to an explosion during the second pulse burn on one of the last test articles. The company also had great difficulty in mixing the fuel--a technique that Lockheed had perfected. Lockheed finished out the FY 1973 production run by producing all 480 motors (since Thiokol had not qualified as a source), but at the price quoted within the competitive environment. Lockheed produced 545 units in FY 1974 at a negotiated price of $58,200 a unit.

Through an audit of the final costs to Lockheed in supplying the rocket motors, Boeing was convinced that Lockheed did not lose money, even at the reduced prices for the final 2 years of production. In fact, based on FY 1971 prices (as shown in Table C.1), the savings on the remaining buy of rocket motors at lower prices is on the order of $30 to $40 million, net of the $9 million commitment to qualify a second source.* But, lacking any other rocket motor business, Lockheed

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*Boeing views expenditures necessary for dual sourcing as money very well spent on high-risk items from a technological/schedule standpoint. The justification for this kind of expenditure is the possibility of losing the sole source; if the subsystem is unique, there are no other suppliers who can step in when trouble occurs.

Table C.1

PRICE PER UNIT FOR THE SRAM ROCKET MOTOR

(Thousands of 1971 dollars)

Year	Quantity	Lockheed	Thiokol
FY 1971	101	296	
FY 1972	465	117	
FY 1973	478	(110) 67	85 (bid)
FY 1974	545	(81) 47	

NOTES: The prices listed in the last two columns of this table are in thousands of constant 1971 dollars (the rate of inflation used was 7 percent). Thus, they differ from the prices quoted in the text, which were quoted in current dollars.

The calculated savings from competition cited in the text was based on an estimate of the likely prices that Lockheed would have quoted for articles delivered in FY 1973 and FY 1974. The estimates (shown in parentheses in the table) are based on the learning curve revealed by the two earlier years for which there were actual prices. The learning curve has the form

$$\log P = a - b \log Q ,$$

indicating that the unit price will decline as the quantity produced increases. From the data, the estimates are a = 6.64 and b = 0.539; this equation implies a very rapid rate of learning: 69 percent (for each doubling of output, the unit price will decline to 69 percent of its former value). Based on a calculation of total price to the government had Lockheed charged the predicted prices minus the actual price charged, the gross savings on the last 1023 motors are estimated to be $38.2 million.

If we had assumed a more typical rate of learning--a 90 percent learning curve--and had fitted the curve through the actual production quantity and unit cost for the FY 1972 deliveries, the estimated coefficients would be a = 5.49 and (as assumed) b = 0.152. In this case, the estimated gross savings would be $48.3 million. Subtracting the $9 million qualification costs yields an estimate of net savings on the order of $30 to $40 million.

For a more detailed discussion of learning curves, see H. Asher, Cost-Quantity Relationships in the Airframe Industry, The Rand Corporation, R-291, July 1956; or H. E. Boren, Jr., and H. G. Campbell, Learning Curve Tables (3 vols.), The Rand Corporation, RM-6191-PR, April 1970.

subsequently discontinued its production of rocket motors. Thiokol will be the producer for a new, long-life motor for the SRAM. Although Thiokol had not perfected the process for producing the SRAM-A rocket motor as built by Lockheed, it is now in a cost-reimbursable mode of development of the long-life rocket motor.

Boeing's major interest in qualifying this second source was price reduction, but the justification it used was the need to create a viable mobilization base: "In case of war, where would we be if the Lockheed plant in Redlands were blown up?" While Boeing's concern over the vulnerability of a sole source for a critical part of the missile has some substance, price was the key issue in seeking out the new source. Even the threat of competition yielded high payoffs in terms of price reduction. An additional payoff, now that Lockheed has left the industry, is that Thiokol's prior experience with the motor will be helpful to its future work on the long-life motor.

A second example of the use of dual sourcing occurred in connection with the missile battery production. Two sources of supply--Yardney and Eagle-Picher--were retained for the first 3 fiscal years of the SRAM program, both at the behest of the customer and because of the prime contractor's past experience with the vagaries and "black art" of missile battery production (see also Appendix B). In the first year, each supplier built 27 batteries; in subsequent years, between 450 and 500 batteries were purchased from the two companies, based on their bids--the lower bidder received roughly 60 percent of the annual production allotment. By FY 1974, the bid from Yardney was over $1000 more than the quote by Eagle-Picher, so procurement was narrowed to

one source of supply for the remaining 452 batteries procured.* The result of this dual sourcing appears to have been a significant hedge against technical uncertainty in production and a competitive environment for the setting of prices.

Other Supplier Problems

Military Specification vs. Commercial Practice. The Electric Brake Company was approached to build and deliver the brakes for the SRAM rotary launchers. Electric Brake refused to bid on the product with a commitment to furnish the full complement of written documentation required for military procurement. "We are in this business to sell brakes, not paper," was the supplier's comment. Electric Brake did, however, agree to supply systems meeting its own commercial specifications.

Boeing handled the problem by procuring additional units for screening so that it could complete the specifications/configuration certification. This task was performed at Boeing by taking every fifth unit, tearing it down, and inspecting it. None of the units were rejected as a result of this certification procedure, and Boeing was able to complete the documentation in accordance with the specifications. In terms of hardware alone, this documentation requirement added 20 percent to the cost of the brakes.

Perhaps 1 percent of the dollar volume of the business, at least in the aerospace industry, is estimated to be consumed in doing this

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* It is also interesting to note that Eagle-Picher's sole-source quote for batteries for the SRAM-B program as of mid-1976 was considered by Boeing to be very close to recent results within the competitive environment.

type of certification procedure. But as Boeing has indicated, the SRAM itself was a very difficult undertaking from a technological standpoint. It is likely that, in total, most of the specifications to which the missile was built were essential; but for the ground equipment supporting the missile, perhaps some of them could have been considered "excessive." The latter is an area in which reliance on standard commercial practices and products might yield savings (e.g., adaptors, welding, and paints).

The electronic test stations for SRAM-B provide another example of how production cost is increased by adherence to military specifications. The prices quoted by the PRD Electronics Division of the Harris Corporation were accompanied by the comment that "our extensive experience with military-specification-type production indicates that it would cost three to five times as much to design and build these units to military specifications." Further investigation revealed that the only deviation from commercial construction that may be necessary is to build the test stations with some special characteristics so that they can operate in explosive environments. Other experience was cited in which comparable commercial items were available, but the relative cost of producing them to military specifications was two to three times greater than the commercial products.

Change in Corporate Structure and Relocation of Production Operations. Production of the warhead shell (costing $325 each) for the SRAM was relocated during the program. Marquardt Corporation's takeover of a segment of the product line being shifted from Murdock Corporation (both subsidiaries of CCI) required that production be transferred from Ogden, Utah, to Van Nuys, California, a move that

was accomplished between March and October of 1972. Problems arose due to the material used in the warhead shell and the high rejection resulting from poor manufacturing quality. The transfer was further complicated by the fact that a very large, government-owned, shear form machine (manufactured by Hufford) was needed in the production of the shell, and the copy of this machine that was moved did not work well in its new location. Therefore, for the remainder of the SRAM production, materials had to be shipped to Lockheed in Sunnyvale, California, so that one of the few other copies of this machine could be used for the first 2 steps of a 4-step die-forming operation to pull the warhead shell out of a 2-in.-thick section of aluminum.

To remedy these problems, Boeing felt that it had to reevaluate the whole production team. Since new people were involved, Boeing wanted to be sure that they were technically qualified. This evaluation involved sending a resident team from Boeing to Marquardt; in addition, Marquardt assigned both a full-time program manager and a full-time production controller. Initial schedule delays were under control by October 1973.

In the above case, an ongoing production program, and the availability of only a limited number of machines critical to the production process, required a prime contractor to intervene in a subcontractor's operation to sustain the production. Boeing did not find it necessary, however, to resort to seeking an alternative source for further production.

CASE STUDIES OF SUBCONTRACTORS

To obtain better insights into the lower tiers of the industrial base for the production of missile systems, it seemed desirable to study selected lower-tier firms in greater detail. We have selected, from among the problem cases discussed above, two firms for more careful analysis: General Electric and ARF Products.

GE's motor casing division built the rocket motor case for SRAM--making GE (one of the largest firms in the United States) a second-tier supplier for the SRAM-A program. At the time of this research, GE was considering discontinuing production of rocket motor cases and thus dropping out of the program. ARF Products, on the other hand, was entering the program as an alternative source for the command destruct receiver, replacing another first-tier supplier whose performance had not been satisfactory. ARF Products, by the usual definitions a "small business," won the contract entirely because it was well qualified to do the job.

We will briefly discuss these two firms--one large and one small--from the standpoint of the industries they are in and their perspectives on the activities of the SRAM program. We will also briefly comment on each firm's other product lines and their perspectives on defense business in general. As with most case studies, we do <u>not</u> claim that the activities and views of these firms represent broader industry perceptions. They are offered as interesting examples because they spanned a range of industrial capability and firm size, and because they were important to the technological success of the SRAM program.

Producer of the Rocket Motor Case

The Industrial Setting. In 1958, the rocket motor industry as a whole was anticipating a large-volume business from the production of rocket motor casings for ICBMs and IRBMs, and was committing considerable amounts of investment dollars to this end. Estimates were that the business would reach $100 million a year by 1965 and increase in volume beyond that point. But by the late 1960s, it was clear that the volume of business in rocket motor cases of 20 in. or larger would not be more than $25 million a year. Moreover, the competition from alternative materials is increasing and may capture some of the business from steel casings. The Navy, for example, has done well with fiberglass, and Aerojet has been emphasizing titanium.

GE operates its rocket motor case division as a separate profit center. Aside from its work on SRAM, it has produced large cases for the Minuteman and smaller ones for the Phoenix and the SAM-D (Patriot). Other producers of casings include Intercontinental (which uses a rolling and welding approach); Dynamic Enterprises (producing the SHRIKE--a 6-in.-diameter case); and the largest--Norris (producer of Sidewinder cases). Those still actively trying to get new business include Kaiser (a specialist in big nozzles), and Rohr (maker of the Titan case and committed to be a supplier for the space shuttle). A number of firms have already dropped out of the industry, including Allison, Pratt & Whitney, Allis-Chalmers, Westinghouse, and Curtiss-Wright.

SRAM Program. GE took over the development and production of the SRAM rocket motor case after Lockheed had spent several million dollars on its own development effort, and the overall development of

the motor had been delayed by problems with the case. The case had been in the design phase at Lockheed Propulsion for 3 years before Lockheed subcontracted it to GE. When the SRAM motor case was in production at GE, about 50 hourly employees and 20 supervisory personnel were working on the project.* Although GE itself did much of the work on the very complicated construction of the steel motor case, it did buy forgings and also subcontracted some of the work to smaller machine shops.**

According to GE, one of the big problems in defense work is that the volume and rate of production make a big difference in terms of the production processes. However, with a new missile, there are great uncertainties about the final quantity to be produced, partly because of ambiguities in initial military commitments and partly because of the vagaries of congressional support for the program. For example, GE committed $2.5 million in facilities investment for the Minuteman program and considered itself fortunate that the Minuteman continued in production for as long as it did--making it a successful program for GE. But in most cases, the Internal Revenue Service requires depreciation of equipment over a longer period than the certainty of a program permits. Thus, based on experience, GE's policy has been, in general, not to commit its own money to investment in such programs. For some of the machining for the Minuteman rocket motor case, GE used

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*The hourly employees, of course, are particularly dependent on the rate of production.

**In part, this subcontracting was due to the inadequate precision of some government-furnished machine tools that GE had used in its jet-engine business.

Government Furnished Equipment.* Since there were competing contractors (in this case Curtiss-Wright and Allison), GE could not be certain of getting the contract. GE did not want to make large investments of its own in capital equipment because it could not be sure, from one year to the next, of any continuing production commitment.

When the SRAM program was originally conceived, GE estimated that about 3300 SRAMs might be built, in which case numerically controlled machine tools became attractive. But this equipment would have required a $1.5 million investment, and GE would have needed a high rate of production, with several shifts, to make this production process efficient. Moreover, GE could not fully depreciate the equipment in the 4 years of the program. Ultimately, GE dropped plans for numerical control as the quantity of the buy became less certain and, as a result, had to subcontract some of the machining.**

GE had considered dropping out of the SRAM-B program during the planning phase simply because there was not enough business available and thus a limited potential for profit. Its Minuteman production appeared to be ending shortly, which would have created a 2- to 3-year

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*A piece of new government-owned equipment that GE used in the Minuteman program was a roll-forming machine produced by Cincinnati Milacron for making the 16-ft long motor cases. Cincinnati sold the machine on a firm-fixed-price basis for $330,000; it cost Cincinnati an additional $660,000 to produce the machine. Aside from this very large and specialized machine, an X-ray inspection machine that the government requires for inspecting welds (that GE itself finds of little utility), and a few fork-lift trucks, there was no other government-owned equipment in use by GE for its rocket motor case production at the time of this research.

**It is interesting to compare the differences between small and large companies in terms of investment decisionmaking. GE has a decision process (involving capital investment over a half million dollars) that would take a year to complete. A small company may have a faster decision process, but may not have as ready access to funds for the investments required as a larger company.

hiatus between production activities for the rocket motor case profit center. With such prospects, the company was considering abandoning activity in this industry, and could easily have shifted both its capital equipment and plant, as well as its skilled labor force, to the production of aircraft turbine engines.* While our research was in progress, GE reversed its decision to leave the industry, because there was a serious indication that there would be further production of cases for Minuteman.

Thus, while it appeared that both the business prospects and the potential for profit were not sufficiently interesting for GE to continue in the rocket motor case industry, further orders for an existing product still in production encouraged the company to remain. However, if GE had not remained in the rocket motor case business, there would have been a reasonably large selection of other firms that could have undertaken the production of rocket motor cases for SRAM-B. Of course, these firms would not have had the detailed production

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*Half of the plant in which GE builds the rocket motor cases is already committed to production of commercial engines and also does work on military engines. Much of the equipment consists of general-purpose machine tools that could be shifted from one type of production activity to another. Since the rocket motor case division is a separate profit center, it would have been dropped by corporate management had it become financially unattractive. In fact, GE's rocket motor case operation has been described as a $5 to $10 million "island" in a billion dollar business. From that standpoint, the advantages of being part of a large firm are mainly that they have access to large metallurgical laboratories, electronic beam welders, etc.; the main disadvantages are that even when they do well, they don't excite anybody (e.g., if they get a $2 million contract). GE people feel that they are able to sustain this business within such a large corporation mainly because they have kept it as a separate profit center, whereas others (such as Allison) have dispersed the activity throughout the corporation and have "lost enthusiasm."

experience that GE had accumulated in producing the complex motor case for the SRAM-A.

GE's participation in the SRAM-A program had not been without problems. The initial production was much more difficult than GE had anticipated, even based on the knowledge that it had been brought in because Lockheed Propulsion had faltered. The first 150 cases that GE delivered involved significant losses, given GE's firm-fixed-price commitment. Of the items delivered, about 80 percent were accepted by the customer for development test only, and the manufacturing loss rate was about 20 percent. Then, one of GE's production engineers invented a means for providing weld buildups on all four edges of both the lug caps and the cylinder segments to increase the longitudinal weld thickness. Thin spots in this weld had been the cause of the major manufacturing difficulties. Subsequent production yielded nearly a 90 percent acceptance rate, and the remainder were acceptable after only minor adjustments were made. These cases have lasted over multiple firings.

This is just one example of GE's emphasis on high-quality production--quality sought by the firm because of the financial incentives to achieve the product specifications within the contractually specified, firm price.

<u>Other Comments on Doing Military Business</u>. It is interesting to consider GE's perception of the government's "quality" activities--especially "configuration control" and the resident quality personnel from the Air Force Plant Representative's Office (AFPRO)--given GE's clear recognition of the need for high-quality production activities.

From GE's point of view, the contractually imposed "configuration control" is, in effect, a "no change" policy. An example from the Minuteman program was cited. The rocket motor case cylinder produced by GE for 3 years had to be cut into two pieces and then welded back together along that cut. The original process used two cylinders, but GE came up with a better process--rolling the entire cylinder as a single piece so that no cylinder-to-cylinder weld would be necessary. But in order to meet the contractually specified manufacturing process, GE had to cut the cylinder in half and weld it back together until a Value-Engineering Change Proposal (VECP) could be approved. This approval was not forthcoming, according to GE, until OSD Comptroller people came in and asked why such an obviously wasteful and potentially dangerous process had been continued. A weldment in a rocket motor casing is always considered a potentially weak element requiring significant nondestructive tests; and even with these tests all manufacturers have found it to be a primary cause of rocket case burst failures.

Another problem perceived by GE is "ubiquitous quality control." Big companies such as GE, having a large-volume Air Force prime contract business, often have a big AFPRO in residence, whereas smaller firms have Defense Contract Administration Services (DCAS) that make visits only on a monthly basis. When the larger firms accept lower tier contracts, there are parallel paths of "quality control" supervision. The government not only hires the prime contractor to oversee its subs, but also requires that its resident AFPRO team at the sub make inspections. When mandatory government source inspection was required, GE sometimes had to shut down a machine for a day so that the inspection

could be made. The scheduling of operations for such inspection is very burdensome. The costs of dealing with the AFPRO are never explicitly shown in the contract. Overall, in the last 15 years, GE's rocket motor case operation has had AFPRO quality "supervision" with little perceived benefit to the government, since the prime has a resident inspector and the product is again inspected by the prime upon receipt.

This GE division also emphasized the burdens of some of the government-required paperwork. In particular, it pointed out some basic problems with the accounting practices. For example, the company has been directed to procure forgings from sources not complying with the Cost Accounting Standards and then has been forced to apply for waivers. When these waivers are received, GE must justify the prices paid. Overall, GE's motor case division operates entirely on a firm-fixed-price basis, an approach the division prefers because it eliminates some of the administrative burdens.

GE views the government's auditing process as particularly burdensome. It requires months of effort to supply the data demanded. In GE's contracting environment, it often starts out as a competitive fixed-price bidder. This was the case for SRAM. But then it becomes a sole-source supplier and the auditors get involved. The auditing process is perceived by GE to be very unrealistic. GE finds that it just cannot pin down what the absolute costs are going to be on some difficult or uncertain activities--i.e., not with the kind of precision demanded. There is always a wide and unresolvable divergence between the GE and DCAS forecasts for maintenance, benefits, manufacturing losses, rent, and supply costs. Had it been forced to accept the

recommended DCAS pricing, GE believes that it would have suffered major losses over the past 4 years.

Producer of the Command Destruct Receiver

The Industrial Setting. A command destruct receiver (CDR) is used during the test phase of missile programs; if something should go wrong during the testing of the missile, the CDR receives the signal from the ground to destroy the missile. Since they are only used for test firing, CDRs are produced in relatively small numbers, even for a large procurement of missiles. They are sometimes purchased directly by the test facility, as the White Sands Missile Range (WSMR) often does for Army testing.* Or they can be produced for purchase by the prime contractor of the missile program itself, as was the case in the SRAM program.

The principal firms producing CDRs are Acctron, Cincinnati Electronics, and ARF Products. In the early 1970s, ARF produced about 100 CDRs per year. The total demands for these devices are not large in absolute dollar terms; most CDRs have sold for less than $5000 each in recent years. Each of the missile ranges tends to have its own specifications for CDRs; and a CDR produced for a particular program for the prime (as in the case of the SRAM) may also have its own peculiar specifications. Thus, it is difficult for any of the firms to manufacture a product that satisfactorily meets the specifications of a particular customer and is low priced. In past years, ARF Products has tended to be a regular supplier of CDRs to WSMR, and

*The Vandenberg Air Force Base test range also purchases CDRs directly.

Acctron and Cincinnati Electronics have tended to be regular suppliers to Vandenberg's test range.

A brief sketch of the background of ARF Products may be useful at this point. ARF was founded in 1942, when it began doing work for the military on small, two-way radio communicators (AR-11) built at the request of the Office of Strategic Services for use by the Polish underground and U.S. forces. Arthur Maciszewski, the current President of ARF, was the designer of the AR-11 and one of the founders of the firm. Over the years, ARF has been a prime contractor on many types of small military electronic gear, and has worked for many government agencies--including the National Bureau of Standards, the Civil Aeronautics Administration, and the National Aeronautics and Space Administration, as well as all three of the military services. It has produced commercial products, including electronic door-openers, modularized test equipment for college chemistry laboratories, molded ski boots, hi-fi equipment, and water purifiers.* ARF was originally located in suburban Chicago. But in 1952, after the federal government expressed concern over geographical dispersal of defense contractors, Mr. Maciszewski decided to move his company to the southwest, locating it in Raton, New Mexico. In 1963, ARF set up its R&D facility in Boulder, Colorado, to be near the University of Colorado and scientific-based firms in that area.** The firm's total sales have

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*ARF also attempted to enter the guitar-amplifier business but aborted the project in the early 1960s.

**One of the reasons for locating the research and development facility of ARF Products in Boulder was to have access to sophisticated test equipment and other facilities that are available in other corporations located in the area. ARF would also have access to a relatively more sophisticated labor base in Boulder than exists at the corporate headquarters in Raton, New Mexico.

been as high as $4.5 million annually. In 1976, with 115 employees, it was doing about 2 million dollars' worth of business. ARF's military work has declined from 80 percent to about 20 percent in recent years, largely because it finds that there simply is not as much defense work as it would like to undertake.

SRAM Program. ARF Products became the subcontractor to Boeing for the command destruct receiver for SRAM after Acctron had difficulties in meeting its commitments.* When Boeing turned to ARF Products as the alternative source for this unit, it entered into a three-phase contract. In the first phase, ARF was to develop an engineering model of the command destruct receiver. It accomplished this task by improving the version that was already being used by WSMR. This phase of the contract took approximately 2 months to complete. During the second phase, ARF built a prototype of the unit, including refinements in its construction so that the prototype would be a facsimile of the final product. This phase of the contract took approximately 3 to 4 months. The third phase consisted of qualification testing; a number of the elements of the qualification test were performed at corporate or government facilities in the Boulder area.

During the entire production program, quality assurance was given high priority. Not only was there a testing program, but Boeing retained a staff member in residence for the entire production period. In addition, ARF was supposed to be monitored by the Defense Contract Administration Service (DCAS). However, because ARF was working as a

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*See the discussion under "Acceptance Test Difficulties," above.

subcontractor to Boeing, and since it already had two "quality people" fully employed with the paperwork, as well as the Boeing resident representative, the DCAS signature of acceptance on these CDRs was essentially a "blank check"--an advance authorization. In other words, the DCAS representative took the practical view that with all of the oversight already being applied to ARF's production activities, requiring the company to wait for the relatively infrequent visits of the DCAS representative would only delay production delivery and was not warranted.

One of the specialized contracting practices applied in the SRAM program that ARF had not been required to meet in the past had to do with piece-part traceability. The objective of this requirement is to provide a documentation of the origins of the various batches of components used in different products so that if a problem occurs in one unit, all other units having that potentially defective component from the same batch can be found. In practical terms, however, this requirement for strict documentation of piece-part traceability allowed ARF to acquire, at Boeing's (and ultimately at the Air Force's) expense, a minutely detailed corporate record of how to build a command destruct receiver. Had ARF been selling this unit to some other buyer who did not demand this kind of traceability, it would not, on its own, have made the investment necessary to develop this kind of record. In this case, piece-part traceability was required, and all the circuit boards were serially numbered so that there could be a complete written history of each CDR. One of the side benefits to ARF was that it now has sufficient documentation to enable it to train a new employee to build a CDR. In fact, we were informed, with the written records now

in existence, "anybody who can read can build a command destruct receiver."

The cost of this contractual requirement can be fairly easily determined. ARF has produced CDRs for the Army, which does not require piece-part traceability, and for the Air Force (in this case, the SRAM), which does. The price of the CDR with piece-part traceability is about twice that of a comparable CDR without it.

Two other features of the stringent requirements for CDR in the SRAM program may be worth noting. First, when ARF has produced CDRs for WSMR, it has used plastic-encased transistors. However, these transistors are not acceptable to the Air Force. So, for the SRAM program, ARF not only had to change the design of its CDR but also its vendor, because the vendor for this particular transistor does not make metal-encased transistors. The ultimate result of this requirement was thus a redesign of the complete unit, and a consequent increase in cost.

Second, part of the acceptance testing done on command destruct receivers can create a problem because of the vibration failure associated with its components. It was perceived that requirements for redundant testing would increase the probability that the CDR would fail when it was actually needed.

In comparing the practices of the Army and the Air Force with respect to this one very specialized product, ARF observed that the more pragmatic concern for obtaining a product that functions as it is supposed to is more likely to yield an effective and reliable product at a lower price than if detailed specifications are imposed and documentation of quality assurance is required.

Other Comments on Doing Military Business. Although ARF Products is a small firm by most standards of measuring firm size in the defense sector, it has been in business for over three decades and has successfully designed and produced relatively sophisticated electronics gear. It would appear reasonable to conclude that if the DoD wants to sustain the viability of small, high-technology firms in defense work, ARF is a likely example of such a firm.

One of the main problems ARF faces in continuing in defense work is that, for the last several years, there has been a decline in demand for their products. As a consequence, the probability of their receiving a contract based on their response to a request for proposals has also declined. Since the costs of writing proposals have not declined, it is becoming increasingly more expensive for ARF to stay in the defense business. From the top management of this company down, there are very strong personal preferences for continuing to support the U.S. national security effort. However, the practical economics of the situation makes such participation increasingly difficult.

FINAL OBSERVATIONS ON THE SRAM

In summary, the problems encountered during the SRAM program seem to have been largely those of technological difficulties leading to changes in source of supply, and occasionally to prices higher than competitive forces would allow. The price problem was not due to an inability to generate competition but more often to the lack of encouraging competition. When competition was sought, prices were brought down.

Even though SRAM has gone out of production, there is good evidence that it would be possible to resume production without encountering a number of suppliers and subcontractors who would be unwilling to participate in defense business. In fact, it was explicitly pointed out to us that one of the advantages of doing business with the government is that it enables many firms to enhance the state of the art in their technological areas while working under government funding.*

*At one time, defense contracts were a stable business and could be counted on to cover at least some of the firm's fixed overhead. This is no longer true.

Appendix D

SPACECRAFT*

Our approach to data gathering in the Space and Missile Systems Organization (SAMSO) varied somewhat from that used for ASD programs. We focused only on satellites.** We did this for two reasons. Satellite systems and some of the products used in or related to them have commercial counterparts--e.g., communication systems. Since the existence of a commercial as well as a military market for technologically sophisticated products is fairly rare, we thought it would be useful to compare the two. Such a comparison could yield useful information about the relative ease with which firms move from one market to another and about whether or not there are price differentials for relatively similar products (and, if so, why). Also, an examination of the industrial base that supports the Air Force in the development and procurement of satellite systems was complementary to other on-going Project AIR FORCE research on spacecraft acquisition.

As the research progressed, the information we gathered suggested that the commercial and military products are more distinctly different than we had believed, and that these differences have resulted

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*The research reported in this appendix was done by D. Dreyfuss and A. Gandara.

**In the course of this research, representatives of three SAMSO directorates (Space Communications Systems, Defense Meteorological Satellite Systems, and Space Navigation Systems) were interviewed.

in the evolution of fairly separate military and commercial industries, thus limiting the potential for useful comparison. Also, since the demand is for very small quantities of highly sophisticated products, the supporting lower tiers of the industrial base are relatively small--both because there are few prime contractors, and because the primes tend to do much less subcontracting than other military producers. Notwithstanding these comments, the following analysis of spacecraft and one particular satellite component, the traveling wave tube, does provide insight into the condition of a segment of the defense industrial base that is important to the Air Force.

OVERVIEW OF SATELLITE INDUSTRY

Let us begin our enquiry into communication satellites with an overview of the manufacturers. A look at their past and present production will provide some insights into the market's needs and the total manufacturing capacity of the industry.

Military Manufacturers

Hughes Aircraft. Hughes has long been in the forefront of communication satellite technology. It built the experimental Tactical Satellite Communications System (TacSatCom), which is still operating, although its performance has recently deteriorated. Hughes is also building a Maritime Communications Satellite System (MariSat) that comprises three satellites for all maritime communication carriers, including the U.S. Navy. The MariSat satellites could be considered commercial, since they are contracted for and owned by Comsat General, which, in turn, leases several channels to the Navy.

Lincoln Laboratory. Lincoln Laboratory of MIT has also built a series of communication satellites, the latest of which is the LES-8/9. Not much information about this series is available except that it is concerned with physical and electronic countermeasures survivability. The LES-8/9 satellites, which will partially compromise the DoD's SurvSatCom program, were launched in March of 1976.

Philco-Ford. Philco-Ford built the first repeater communication satellite--the Courier--in 1960 for the U.S. Army. In the mid-1960s, Philco-Ford built twenty-seven satellites for the Initial Defense Satellite Communication System (IDSCS). This company also built the Skynet I satellite for Great Britain and is currently building two NATO III satellites.

TRW. TRW is now the major producer of communication satellites for the military. In 1969, the IDSCS designation was changed to DSCS (Defense Satellite Communications System), which is one of the major communication systems in the World Wide Military Command and Control System. TRW has delivered six satellites for the DSCS-2 program and is building six more. It is also building four satellites for the Navy's Fleet Satellite Communications System (FLTSATCOM).

Commercial Manufacturers

Fairchild Space & Electronics. Fairchild's entry into this field was via NASA's Applications Technology Satellite Program. Fairchild designed, built, and tested the ATS-6, which was the world's largest and most powerful communication satellite and the first three-axis stabilized communication satellite in synchronous orbit.

The satellite was built for NASA and, strictly speaking, is not a commercial satellite. However, most of its experiments are

commercial in nature and Fairchild apparently intends to exploit its acquired expertise in the commercial market. (Fairchild filed with the FCC for a license to operate as a common carrier and was instrumental in forming the American Satellite Corporation.)

<u>General Electric</u>. General Electric was awarded a contract by Tokyo Shibaura Electric Co. (Toshiba) to build two experimental television distribution satellites.

<u>Hughes Aircraft</u>. Hughes is the major producer of commercial communication satellites. As of March 1974, Hughes had won all the awards from COMSAT (the major buyer for the U.S.), with the exception of the Intelsat III series, which went to TRW.

Hughes built the Intelsat I series (two satellites), the Intelsat II series (four satellites), the Intelsat IV series (eight satellites), and the Intelsat IV-1/2 series (three satellites); it is one of the bidders on the Intelsat V series (seven satellites with an option for eight more). The Intelsat satellites were all purchased by COMSAT for internal communications.

Hughes built Canada's first domestic satellite system, Anik, and the first U.S. domestic satellite system (two satellites) for Western Union (Westar). Hughes is also building four satellites for COMSAT, which are leased to AT&T for 7 years for domestic use, and two satellites for an Indonesian communication satellite system.

<u>Philco-Ford</u>. Philco-Ford was awarded a contract by Mitsubishi Electric Corp. to build two experimental domestic communication satellites for Japan.

<u>RCA-Astro Electronics Division</u>. The Astro Electronics Division of RCA is building three satellites for RCA Global Communications, Inc. This system will provide communications to all 50 states.

TRW. As mentioned above, TRW built eight satellites for the Intelsat III series. It has been speculated that COMSAT awarded the contract to TRW to develop an alternative source of space-qualified hardware. However, two of TRW's first three satellites failed to operate, and the contracts for the following series of Intelsat IV and IV-1/2 went back to Hughes.

The Leading Producers

As the preceding overview indicates, Hughes and TRW dominate the commercial and military markets, respectively. Dominance of the market is used here in the sense that the firm has produced most of the satellites in each market category, rather than as a more careful measurement of percentage of market share in terms of annual sales.*

Hughes' dominance in the commercial market is due primarily to its early market penetration and to its exploitation of Hughes-developed technologies. As early as 1959, when satellite technology was in its infant stages, Hughes proposed a spin-stabilized synchronous communication satellite design to NASA. This design was to become the mainstay of the commercial market. Hughes' plan was for a high-altitude, synchronous, spin-stabilized system using three satellites in high orbit to provide total earth coverage. Following Hughes' proposal to NASA, Project Syncom was initiated as a joint NASA/DoD effort. In July 1963, Syncom II became the first successful synchronous communication satellite. The success of Syncom II and III proved the

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*Annual sales are difficult to determine because budgetary data give figures for projects without separating spacecraft procurement from all the other project expenditures. Thus, a disaggregation and apportionment of expenditures to a particular project for a particular year is difficult.

feasibility of the concept, and Intelsat I, built by Hughes, was launched in 1965.

Hughes exploited its lead in this technology fully. The firm perfected the spin-stabilized technique and nutation damping to prevent wobbling. Hughes has concentrated its efforts on exploiting proven technology to provide commercial satellites with long operational lifetimes. Since a commercial satellite typically needs to be in operation for about 4.5 years for initial investment to be recovered, Hughes tries to design for a minimum operational life of 7 years.

With the exception of TRW's introduction of the despun antenna in the Intelsat III series, Hughes has built the entire Intelsat series by using modest advances in spin-stabilization technology. Although the introduction of the despun antenna was a useful contribution in that it provided an increase in effective power radiated, TRW's overall participation in the program was not very successful.

TRW has been more involved in the development of new technology that is particularly useful for military purposes. Its three-axis-stabilization design permits larger payloads and variation in antenna designs. For security reasons, three-axis-stabilized systems are particularly well suited to precision observation and transmission; they are therefore very well suited for most military applications. TRW's experience with three-axis-stabilization designs, as well as with some variations of the spin-stabilization technique, has enabled it to win almost every military competition in which performance requirements were more rigorous than for a typical commercial program. Where the military's needs have more closely approximated those of commercial applications (i.e., simpler performance requirements over

a long lifetime), Hughes has occasionally won. Basically, however, Hughes dominates the commercial side of the market and TRW the military side.

SUBCONTRACTING*

In general, there is less subcontracting in the satellite industry than in aircraft or missiles. Hughes officials estimated that 20 percent or less of the dollar value of a program is subcontracted, as compared with 50 percent or so in an aircraft or missile program. For military programs, the volume of subcontracting is often less than 20 percent, although some high-valued components (such as the traveling wave tubes discussed below) may be produced by other firms and supplied to the prime contractor as Government Furnished Equipment.

The primary reason for the low level of subcontracting in satellite production in general, and in military production in particular, is that very strict quality control must be maintained in order to provide the degree of reliability necessary for a system that operates in an environment where repair of failed components is not practical. The prime contractors generally prefer to do as much work as possible in-house to ensure quality and reliability. Although satellites have very high per unit prices, the number produced is small, which is a great incentive for prime contractors to produce them in-house or to subcontract only to firms known to be competent and reliable. Thus, there is little incentive for new firms to consider getting into the satellite subcontracting business.

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*The information reported in this section was obtained from interviews at Hughes and TRW.

Traditionally there have been very few suppliers or subcontractors for satellite systems and components--usually fewer than five for major subsystems. For example, apogee kick motors are produced mainly by Aerojet and Thiokol. Hercules and Rockwell were also mentioned as possible sources. The bearing power and transfer assembly for Hughes' spin-stabilized satellites is manufactured in-house, although at one time Ball Brothers provided the bearings and casting. Ball Brothers is the major source of lubricant for this assembly, although Hughes now also manufactures a lubricant.

The number of solar cell suppliers is likewise quite small. In fact, Hughes was quite worried that Electro-Optical, its only supplier of space-qualified solar cells, would be acquired by an oil company whose only interest would be to develop and produce terrestrial solar cells. So, in a defensive move, Hughes acquired Electro-Optical to guarantee its access to a supply of the cells. Earth sensors, sun sensors, hydrazine tanks, antennas, reaction wheel assemblies, power units, and control thrusters are other examples of components manufactured by only a few firms.

The need to maintain the existing suppliers of highly specialized products (as in the solar cell example above) seems to be the cause of most of the problems, or potential problems, in the industry. The extremely rigorous quality-control requirements motivate the prime contractors to take decisive action to ensure their access to suppliers of components that meet these requirements. For example, TRW recently acquired AeroTech, its supplier of power amplifiers. Quality control had been a problem within the firm, so TRW simply bought it out to ensure that its product would be acceptable. TRW has also had

difficulty with its only supplier of microswitches. The product has been of consistently high quality, but the supplier (a small firm doing other kinds of business as well) has an "independent" attitude that has led TRW personnel to conclude they are vulnerable to possible future loss of a source of supply. In order to hedge against this prospect, an attempt was made to qualify Teledyne as a supplier of microswitches. This attempt was unsuccessful, so the status quo (current access to a highly qualified source that may at some future time decide to stop manufacturing the product) continues. We were unable to determine, however, how this situation would affect the price of microswitches.

Overall, the subcontracting problems in satellite programs seem to be fairly limited (partly because the volume of subcontracting is limited). Where there are difficulties, their main cause is the extremely rigorous technical requirements of satellite production.

TRAVELING WAVE TUBES*

We chose a satellite component, the traveling wave tube (TWT), for detailed examination for three reasons: First, TWTs, like satellites themselves, have commercial as well as military uses, mainly for communications and instrumentation. Second, TWTs are technologically sophisticated products with a relatively high unit price. Third, concern had been expressed in some quarters in the DoD

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*The information reported in this section was obtained from interviews at Hughes Electron Dynamics, Litton Microwave Electonics, Varian Microwave Tubes, and Teledyne MEC. Together these firms supply about 50 percent of the TWTs manufactured annually.

that (a) TWTs for defense uses are unreasonably higher priced than those used for commercial purposes and/or (b) there may be inadequate supplies.

The Product

TWTs are microwave devices that were developed about 25 years ago. They are used as power amplifiers over a fairly broad frequency range. TWTs have supplanted conventional vacuum tubes, and they, in turn, will likely be replaced by solid-state devices in the relatively near future.

TWTs have several applications. Their broad bandwidth makes them very suitable for communications. Almost all the communication satellites (and ground stations, such as the AT&T microwave communications system) use TWTs. Other applications include phased-array radars, drone-vehicle guidance and control, electronic countermeasures (ECM), fire-control systems, and radar-reflection enhancement.

TWTs can also be characterized by waveform (either continuous wave or pulsed), by the materials used in their manufacture (glass or metal), or by the means of particle acceleration (magnetic helix or coupled cavity). The outstanding features of TWTs are: (a) they are precision devices; (b) they use sophisticated materials; (c) they require very tight tolerances in fabrications; and (d) they demand highly skilled workers in their production. It is alleged by the producers that, although science and technology obviously play major roles in the design and production of TWTs, there is more art and "black magic" associated with TWTs than with most other microwave products. This places a premium upon the producers' ability to obtain and keep skilled workers.

The unit cost of TWTs varies as a function of complexity, power level, bandwidth, and most of all, reliability. TWTs for ground-based applications may be priced as low as $600 a unit. Space-qualified TWTs with design lives of 60,000 hours or more may cost more than $100,000 each.

The Industry and the Market

The TWT industry consists of about nine firms, which manufactured approximately 31,000 tubes with a value of $79 million in 1974 and 26,000 tubes with a value of $76 million in 1975. These sales include all types of tubes, for both government and commercial use. Hughes is essentially the only supplier of space-qualified TWTs. Watkins-Johnson is also a smaller supplier, and Varian formerly provided some backup capability (but it was not a significant amount). Of the total of 3000 TWTs sold by Hughes in 1975, approximately 100 were space-qualified. If $100,000 per unit is the average price of a space-qualified TWT, space units represent approximately a $10 million share of the $76 million total TWT market.

Most TWTs are manufactured for government use. (NASA and COMSAT purchases are included here under "government," but are only a small portion.) The very few units sold for purely commercial applications are either for communications or instrumentation. Some of the "commercial sales" have a government end-use. For example, Litton may sell TWTs to Hewlett-Packard, a commercial sale; but Hewlett-Packard may use the TWTs to fulfill a military contract. The market is principally--probably 80 to 90 percent--a government-oriented market.

The TWTs used in satellites are custom designed and more complex than those manufactured for other applications. Further, since TWTs used in commercial satellites are different from those used in military satellites, they operate in different frequency ranges and have different input and output requirements. Hughes is essentially the only supplier of TWTs for military satellites, but commercial satellites have a slightly broader base of supply. European firms such as Telefunken and CSF-Thompson have been developing high-frequency, high-power TWTs that may enable these firms to make inroads into Hughes' share of the market.

No TWTs (whether for space or other uses) are manufactured for inventory. All production units are unique designs and require some research and development effort prior to production. The key to lowering the unit price, according to representatives of both Litton and Hughes, is to develop a reasonable production rate that remains steady over the life of the production run. None of the firms indicated problems with retaining adequate subcontractor support, and the amount of subcontracting generally varies according to the complexity of the TWT. Manufacturers of the most sophisticated devices tend to produce them in-house in order to provide work for their skilled labor forces and to maintain effective quality control. The less-sophisticated TWTs are more likely to be subcontracted.

Communication satellites usually require one TWT per channel. Some of the earlier satellites had 12 channels with a redundancy of one TWT per channel, or 24 TWTs per satellite. Even though the newer satellites may have 24 channels, the increased reliability has reduced redundancy and so there may be only 36 TWTs. The basic

point is that few TWTs are used in a satellite and few satellites are produced.

Although the production volume and space applications (DoD and commercial) for TWTs are generally small, other DoD demand for this component is highly variable. At the height of the Vietnam war production, for example, TWTs for ECM were in great demand. Since then, however, the market has gradually declined. In 1976, Litton went into a major but short-lived (about 9 months) production surge to provide spare TWTs for the B-52 ECM system. This surge, which was accomplished at a severe dislocation of Litton's other production schedule, came about because of Air Force demands when spares were in short supply. Litton contends that the DoD does not plan very well for smooth production, which in the long run would result in lower unit costs.

Since the market for TWTs is largely government-oriented, market segmentation by firms tends to be along the lines of type of product rather than military versus commercial. For example, Hughes' segment is space-qualified TWTs; Varian's is high-powered TWTs; Litton and Teledyne concentrate on ECM applications; and other firms produce low-noise tubes. For any firm to increase its share of the market, it must engage in competition for other firms' business, and at the same time retain its own market segment. This puts an effective lid on a firm's ability to grow; further, it limits entry of new firms into the market because it places them squarely against entrenched companies with strong market positions.

Varian's experience in producing space-qualified TWTs provides an example of how these divisions have evolved. Varian used to make

space-qualified TWTs but eventually stopped manufacturing them because it could not get a big enough share of the market away from Hughes to make production profitable. Varian personnel indicated that the company probably would not go back into the manufacture of space-qualified TWTs because to do so would very likely cost them at least $1 million in investment capital. It was the Varian representative's opinion that if another TWT manufacturer tried to compete in the space-qualified market, it would cost $5 to $10 million. This investment (either for Varian or any other firm) could not possibly be justified on the basis of expected return.

Pricing Policies and Degree of Competition

Although we tried to examine how pricing policies are affected by target rates of return on investment, we were unable to obtain financial data by product line, so our conclusions are, of necessity, largely speculative. Despite the lack of hard data, Teledyne representatives, for example, stated that the ASPRs and renegotiation provisions set upper limits on rate of return and that Teledyne never comes close to reaching these upper limits. Hughes personnel stated that the company tries to make 10 percent (after tax) but considers itself fortunate to make 5 percent, mainly because of cost overruns. Varian officials only indicated that the company makes more on klystron tubes than on TWTs (but it has very little competition in the klystron field). Litton representatives said that when Litton is the sole source, it tries for a 15-percent rate of return but seldom gets more than 12 percent. However, the company's average rate of return is less than 12 percent because it loses on some production contracts and on most development efforts.

Even though there is little commercial TWT business being done by any of the firms, all personnel stated that there is no difference between the rate of return on DoD sales and commercial sales. In fact, because it has to pay commissions on commercial sales, Hughes claims to net less on them than on DoD sales. It may well be that because of current over-capacity in the production of TWTs (estimated production volume is about 50 percent of capacity), the rates of return are low. Overall, company-wide rates of return may be higher, partly because of the higher prices charged on other products in less-competitive markets where the DoD may also be a client.

Although the reliability of information not supported by hard data may certainly be questioned, it does appear that the TWT market is quite competitive. The possible exception is the market for space-qualified TWTs, which is dominated by Hughes. However, as mentioned earlier in this discussion, European competition may become a factor in this segment of the market. Further evidence of competitiveness is provided by the fact that there are usually several responses to every DoD Request for Proposal.* Despite unpredictable economic conditions of the recent past, and the difficult nature of TWT production, firms still make firm-fixed-price bids because of competitive pressure. This is often true even for contracts that involve a substantial amount of development. When a firm does express reluctance to enter into an agreement that would require company investment in some R&D, as happened recently with Teledyne and with a contract for

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*Some of the industry representatives interviewed bemoaned the scarcity of sole-source contracts.

TWTs for P-3A ECM, there are alternative sources available. On the whole, the TWT market seems to be competitive, and no problem currently exists in finding qualified firms to produce for the expected DoD market.*

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*For a more detailed analysis of longer-term trends in the TWT industry, see the discussion on entry and exit in various segments of the defense industrial base in Section IV of R-2184/1-AF.